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Guidelines for those who are responsible for and directly concerned with the improvement of science instruction are presented. Problem areas relative to science instruction in grades 7-12 are: identification of essential ideas emphasized in modernized courses; delineation of the laboratory as central in science learning and investigation practice; encouragement of the professional advancement of teachers; exploration of multitrack courses or sections, and investigation of the place of science in the comprehensive high school. Specific subject matter areas are discussed, along with descriptions of ongoing nationwide curriculum developments in science courses. Recommendations are made regarding time allotments for science courses, teacher training and assignment, and equipment and resources available for science instruction. Suggested sequences for a six-year science program, grades 7-12 for nine tracks, are arranged in chart form with an analysis given of each.

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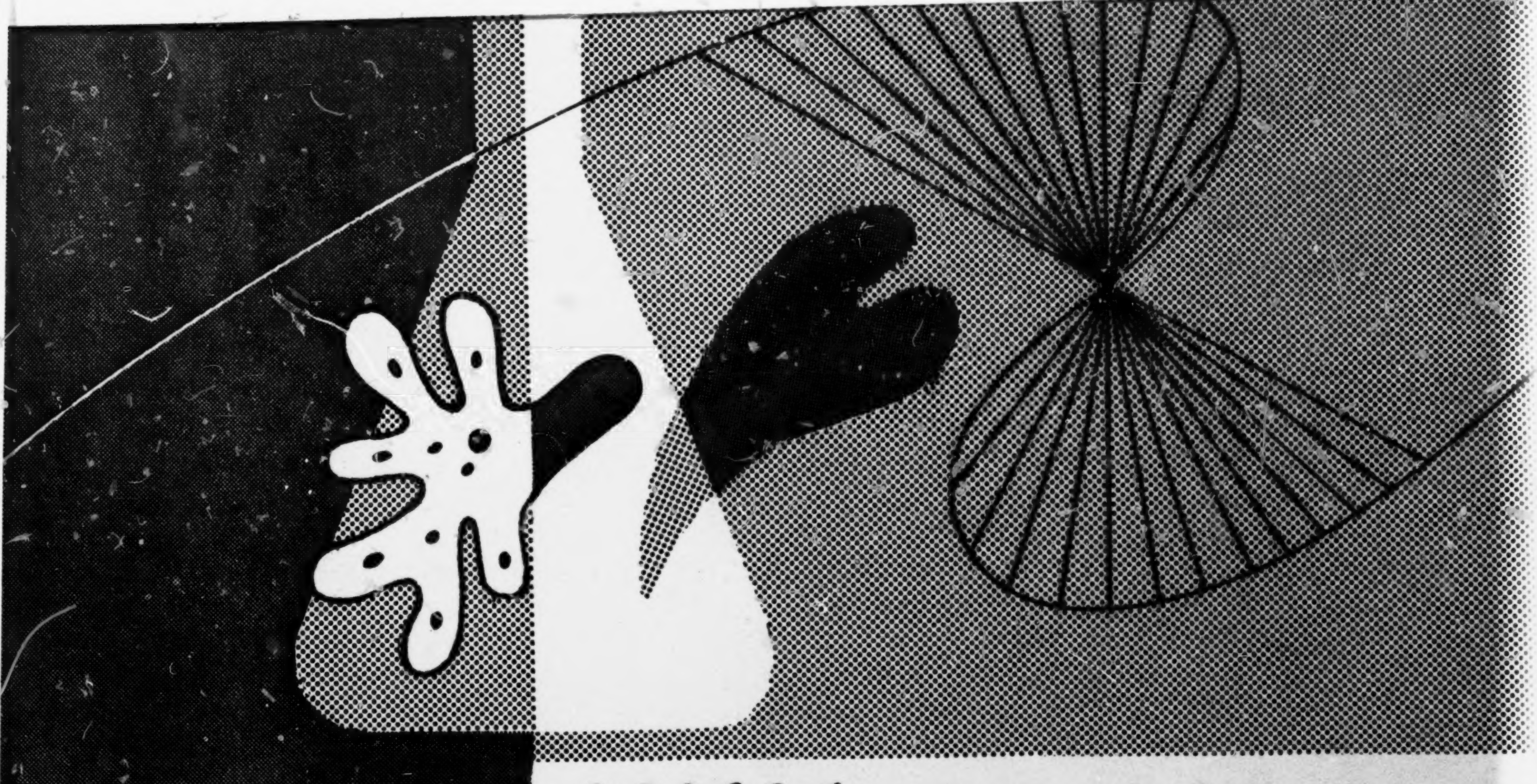

REPORT of the

STATEWIDE ADVISORY COMMITTEE ON SCIENCE INSTRUCTION IN THE HIGH SCHOOLS TO THE SUPERINTENDENT OF PUBLIC INSTRUCTION

CALIFORNIA STATE DEPARTMENT OF EDUCATION
DIVISION OF INSTRUCTION - BUREAU OF SECONDARY EDUCATION

SCIENCE CURRICULUM DEVELOPMENT IN THE SECONDARY SCHOOLS

A Report of the

Statewide Advisory Committee on Science Instruction In The High Schools

to the SUPERINTENDENT OF PUBLIC INSTRUCTION

Educational Materials Laboratory
Office of Education

DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

CALIFORNIA STATE DEPARTMENT OF EDUCATION
APRIL, 1964
DIVISION OF INSTRUCTION - BUREAU OF SECONDARY EDUCATION
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FOREWORD

This is a report submitted to the Superintendent of Public Instruction by my Advisory Committee on Science Instruction in the High Schools. I am transmitting it to superintendents of school districts and counties for consideration by your supervisory and teaching staffs.

The report seeks to give background for the profound changes in course content and instructional procedures currently in progress. In all science courses the laboratory is becoming of major importance and emphasis. A spirit of inquiry pervades the modern science classroom. Students are coming to perceive science as a continually active enterprise of the human mind.

The guidelines for science instruction contained in this report should assist high schools to reduce the pedagogical lag between present scientific knowledge and the substance of secondary school teaching. Its purpose is to help teachers to convey to students deepened understanding of basic principles and their application to human living in the decades ahead.

Max Rafferty

Superintendent of Public Instruction

PREFACE

Science Curriculum Development in the Secondary Schools has been prepared by the State Advisory Committee on Science Instruction in the High Schools. It is designed to give guidelines to those who have responsibility for and are directly concerned with the improvement of science instruction.

The Advisory Committee was organized as a result of the concern of the Superintendent of Public Instruction for improvement of the over-all program of science instruction in the high schools. A group of scientists was called together by the Bureau of Secondary Education at Los Angeles, April 15-17, 1962. This group recommended the organization of a statewide advisory committee.*

Upon appointment the Advisory Committee accepted as its role the task of assisting the Department and school administrators to interpret the numerous ongoing efforts of school districts, counties, colleges, and universities to improve science instruction. Problem areas relative to science instruction in grades 7-12 have been investigated. Among these were:

1. Identification of the essential ideas emphasized in the modernized courses developed by the Biological Sciences Curriculum Study (BSCS), the Chemical Bond Approach Committee (CBA), Chemical Education Materials Study (CHEM Study), and Physical Science Study Committee (PSSC). It was believed that the charting of these concepts and principles could make evident the mission of the high school science curriculum and afford insight respecting:

    1.1 The subject matter of sciences in terms of manageable proportions to be taught;

    1.2 Interrelationships among the scientific disciplines which may reinforce learning; and

    1.3 An over-all picture of science instruction for teachers and administrators.

---

*"Suggestions for the Improvement of Science Instruction in California Secondary Schools, Grades Nine Through Twelve," California Schools, XXXIII, No. 10 (October, 1962), pages 379-381.

2. Delineation of the laboratory as central in science learning and practice in investigation.

3. Encouragement of professional advancement of teachers.

4. Exploration of multi-track courses or sections to make science available and useful to more students with differing occupational objectives.

5. Investigation of the place of science in the comprehensive high school.

In this report the philosophy, trends and objectives of science education are briefly set forth. Specific subject matter areas are discussed along with a description of ongoing nationwide curriculum developments in science courses. Modern ideas about methods of presentation and the importance of laboratory work are reported. Recommendations are made regarding finding time in the crowded school day for science courses, teacher training and assignment, and the equipment and resources available for science instruction.

Richard M Clowes

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Chapter I

INTRODUCTION - A PERSPECTIVE OF SCIENCE EDUCATION

Youth today need scientific knowledge. They are living in an age when men are probing the mysteries of outer space, learning the tantalizing secrets of the deep sea, establishing facts about the mechanisms of genetics and the origins of life, challenging the scourge of disease, in fact, striving to understand the very nature of the planet on which they live and its relationship to the rest of the universe.

The same scientific principles that lead to man's richer existence, can be applied to man's destruction. Decisions of governments are influenced by the dramatic technology achieved through science. Even the daily work that men must do follows a new technological pattern. Because science has impact upon every phase of man's existence -- vocational, social, political, economic, cultural, survival -- it is desirable to be scientifically literate. Every citizen should know enough about the physical and biological world around him to be intelligent in making decisions and in attacking and solving his personal and environmental problems.

With scientific literacy as a goal in planning the high school curriculum, how much and what kind of science instruction should be provided?

As students become acquainted with the scientific heritage that is theirs, what skills and insights should they expect from the instruction they receive?

What are some of the specific conclusions that educators should reach with regard to the science program and the students to be served?

- All students can profit to a degree from science instruction, regardless of their expressed interest or indicated ability.
- The public school system should provide the formal opportunity for everyone to attain a degree of literacy regarding science.
- Subject-matter content must be selected that will be of maximum benefit to all students -- the slow learner and the fast learner, the terminal student and the college-bound student, the non-science major and the one for whom science and technology are primary vocational objectives.
- Decisions regarding instructional goals and also the place of science in the secondary school curriculum should be based

primarily upon what is sound for the student, and not on administrative convenience.

- The student will be served best if he is provided with the opportunity for continuous science instruction, grades K-12.
- Every student in the secondary schools should have the privilege of personal laboratory experience.
- Every student should attain an insight into the intellectual process by which scientific knowledge develops and into the theories and laws that are the products of this process, as well as the acquisition of knowledge about the facts of science.
- The science courses must provide:
  - (a) background for future course work.
  - (b) information of cultural value.
  - (c) skills and understanding that are fundamental to living more effectively in a science-oriented and science-dependent society.
  - (d) knowledge that is either directly or indirectly vocational in nature.

In view of these beliefs, an understanding of both the development of scientific knowledge and of the trends in methods of teaching this knowledge must be considered. Guidelines for improved programs of science instruction can evolve through study of these trends and of the major ideas of science. Finally, school boards, administrators, and teachers need to know the results of such study.

Our society and the needs of our citizens are changing. California's agrarian economy could, at one time, absorb many individuals with limited education. Technology has not only reduced farm-labor requirements in relation to the population, it is also largely eliminating the need for unskilled labor in industrial installations. Thus the vocational character of our society is changing and there will continue to be a progressive increase in the number of scientists and technologists required by our state and our nation. Every citizen has increasing contact with scientific knowledge and with the products of the technology of science. The explosive development in science and technology has world-wide repercussions. The result is a need for a scientifically literate citizenry.

The public schools must therefore provide a program of science instruction to meet the cultural and vocational needs of our society. The establishment of such a program requires concerted planning and continuous evaluation and revision by teachers, supervisors, administrators and laymen. Any "master plan" established today will be a compromise and certainly will need modification before ten years have passed. Some necessary change in science instruction appears to be underway:

1. Central concepts, or themes, now often highlight the interrelationship of the disciplines from which the body of scientific knowledge is gained.

2. The methods of science, those processes by which the scientist achieves his results, are receiving greater attention in the teaching of science.

3. The "inquiry" approach aims to discover answers through questions rather than to verify information already presented.

4. Understanding of fundamental principles is now considered to be of primary importance; factual knowledge provides the structural base for establishing principles.

5. Science is being recognized as a creative intellectual pursuit -- as a cultural achievement of mankind.

6. New methods of testing and evaluating pupil achievement are being developed. Many existing methods of evaluation are not valid for the new methods and aims of science instruction.

7. In secondary schools the conventional course-sequence is being questioned and modified.

8. More attention is being given to science in the elementary grades (K-6) than previously. The result is an increased need for a comprehensive articulated program for K-12 or even K-16.

9. New and better teaching materials are available. Many are adapted to special methods of instruction.

10. The resources, human and material, of communities are aiding in curriculum development, in instruction, and in counseling.

11. National agencies and local industries are progressively increasing their support to students, teachers and schools in their science programs. National Science Foundation grants especially contribute to the training of science teachers.

12. Many school districts are encouraging their teachers to try new programs and to develop new curriculum materials for science instruction. In some cases districts have even provided released time and extended summer employment.

13. Longer school days and summer sessions have become common practice in many districts.

14. A few efforts are being made to devise more functional science courses for the less able student. Programs for the gifted students are appearing.

15. Modern laboratories provide better and more functional facilities, and additional improvements are anticipated.

16. Teachers make more effective use of science laboratories:

    a. Activities emphasize development of principles and experimental solutions to problems rather than verification of anticipated results.

    b. Responsibility is placed on the student through general rather than specific directions; this increases the possibility that the student will think critically and discover relationships himself.

    c. "Open-ended" experiments arouse interest in additional discovery.

    d. Flexible schedules allow for extension of time in the laboratory.

    e. Junior high schools provide student laboratory experience.

    f. Student-made devices illustrate procedures and aid in the understanding of elementary principles. This is especially true in junior high school classes.

    g. Long-range sustained experiments are more prevalent, particularly in the biological sciences.

    h. Individual studies and projects by students are encouraged.

To the secondary schools each of these trends poses a problem of adjustment. Gathering the essential data, outlining curricula, and disseminating information are the responsibility of every science educator. The students will adjust to each new program as it is initiated if some semblance of uniformity and continuity of change exists. The teacher will do his share if he has the (1) opportunity to obtain adequate training, (2) freedom to develop ideas, (3) facilities for laboratory and demonstration, (4) reasonable class size and teaching load, and (5) administrative encouragement. The administrator will make changes possible if the place and scope of science in the curriculum are justified, and if the methods of insuring improved instruction are made clear to him. The board of education will authorize the implementation of science programs if it is provided with sufficient data. The taxpayers will vote funds if they are informed of the urgency of the program.

The combined efforts of those who thus are concerned with education will create a citizenry that will be able more effectively to appreciate and to adapt to the demands of our complex technological world. Every individual now feels the impact of science and its technology; this impact is an inescapable part of his immediate environment and of his future.

Living in the world today is enhanced by an increased degree of scientific literacy. Literacy with regard to science, as used here, implies some understanding of the what and how of science. Understanding means to comprehend (1) the processes of investigation and interpretation by which science advances, and (2) the fundamental laws and theories of nature that are the outcome or products of this scientific process. Acquisition of the knowledge of these scientific processes and products can be achieved best through formal education in science.

As in many other areas of academic endeavor, education in science helps promote intellectual curiosity and an understanding of the world in which we live. However, there are certain educational outcomes for which a study of science is singularly well suited. For example, students who have acquired a degree of scientific literacy can and may:

a. profit by the unique experiences of problem-solving in the laboratory. This is particularly true when quantitative measurement is involved.

b. understand and act in accordance with meaningful concepts of the interrelationships between living things -- including man -- and their environment.

c. organize facts and data meaningfully; interpret these in terms of fundamental principles and conceptual themes which are guides for understanding and for action.

d. devise explanations based on observed evidence, and examine the consequences of assumptions which are based thereon.

e. examine new information and assertions with curiosity and skepticism, thus participating in the self-verifying character of science.

f. inquire effectively into new areas of knowledge which are of interest, thus practicing self-education, the only pattern through which one can keep informed continually in a changing world.

g. acquire an insight into how this learning has evolved and become increasingly able to extend further learning by themselves.

An adequate analysis of the role of the schools in promoting these outcomes of science education must consider the nature of science itself.

Science has achieved maturity, and is one of the several great areas of our culture, although to some, science still appears as an overwhelming body of laws, formulas and facts. Science also is often characterized by its highly technical by-products, from miracle drugs to manned space flight. These views are related to science but they are not science.

Science must be viewed as an intellectual, cultural activity. The processes of science involve scientific methods and attitudes, problem-solving and decision-making, the gathering of information and the testing of hypotheses. Investigation and interpretation, the elements of science-process, highlight the nature of the scientist's work. More than any other single word, INQUIRY characterizes the process of science. Students should be helped to see how scientists have, through controlled inquiry, developed concepts of the nature of the universe. Classroom and laboratory procedures should be designed to instill understanding of the science-process, -- its powers and its limitations. This may be achieved through a diverse pattern of personal student involvement in scientific inquiry.

The product of scientific inquiry is not only the body of accumulated knowledge and the basic principles established but also the practical applications. In teaching science these three need to be kept in mind. Facts must be known as a basis for the principles, but memorization of myriads of facts does not insure understanding of science. Skills and techniques need to be mastered for they represent the methods of science. Scientific knowledge, to be of operational value, must include broad fundamental principles -- a limited number of conceptual themes which permeate science and human experience. Technology can not be excluded from science teaching but technology should not be presented as an end in itself. Rather technological outcomes of science should be treated as illustrations of the impact of science on people, as ways of clarifying principles of science in useful applications, and as areas of intense interest for young people. The dramatic nature of technological products appeals to most students. Some of these students may then turn with enthusiasm to the enjoyment of science as a mental discipline. Some will find satisfaction in developing manipulative skills that are so necessary to the maintenance and growth of a science-dependent society.

With these as our views of the philosophy of science and of science education it seems clear that all students, regardless of their expressed interest or indicated ability, can profit from science instruction.

Chapter II

CONCEPTUAL THEMES AND THE SCIENTIFIC ENTERPRISE

The disciplines of science, once regarded as rather discrete fields of human experience and specialization, are becoming increasingly interrelated as their ramifications unfold with the increase and advancement of scientific knowledge. Recognition of this fact has led to one of the most significant trends in science education: the use of conceptual themes as a basis for curriculum development. Such themes serve as "strands" or "great ideas" to be developed to some degree in every science course. The limited number of conceptual themes offered here will serve curriculum workers in several ways: as a basis for selecting subject matter, as a guide to the teacher in determining where thematic emphases should be placed, and as criteria for evaluating any science course as a part of the total science curriculum. Specific suggestions for the use of the thematic approach in the classroom and in curriculum development follow the discussion of the themes.

Conceptual themes in science, for the purposes of this report, are defined as the broadest of basic understandings, summing up the relationships we can recognize in the world of things and events. They serve to pinpoint the fundamental comprehensions and the essential evidences of the order we have come to see in our exceedingly complex, constantly changing environment. These conceptual themes are not to be identified with any particular discipline in science, for the evidence supporting each of them is usually drawn from many branches of science.

In the following list of conceptual themes, no sequence, precedence, or hierarchy of importance is implied.

CONCEPTUAL THEMES COMMON TO THE VARIOUS DISCIPLINES IN SCIENCE

EVERY EFFECT HAS ITS CAUSE OR CAUSES

The basic assumption behind scientific investigation is the belief in cause-and-effect. Within limitations, identical causes produce identical effects, thus making scientific prediction possible. Insofar as man can identify patterns of cause-and-effect, he is better able to control natural phenomena. It should be recognized, however, that man cannot know the present completely, hence he cannot predict the future exactly. Cause-and-effect is an expression indicating the extremely high probability of the occurrence of an event.

When oxygen is produced in the laboratory, certain experience-tested rules are followed and specific materials are used under controlled conditions. If a film badge for detecting radiation shows exposure, we know that some phenomenon has occurred which causes this effect. When a satellite goes into orbit, it does so because conditions and forces acting upon it were properly controlled to achieve this particular effect. When the mutation of an organism is noted, our search for cause -- for we believe there must be a cause or a combination of causes -- becomes a most challenging adventure in science.

SCALES FOR TIME, POSITION, SIZE, AND MOTION IN SPACE ARE RELATIVE, NOT ABSOLUTE

Man has had to learn to observe natural phenomena on (or from) moving "platforms" in space. The primary platform for him is the Earth, but the time is at hand when he must learn to judge and measure time, position, size, and motion as they are observed from other moving platforms.

The scales or units of measurement that man employs to deal with these factors must be chosen in the light of the magnitudes involved, to serve as suitable frames of reference to give his observations significance. Comprehensible scales in size, for instance, must vary from the microcosms of atomic structure and microscopic life, to the macrocosms of the solar system and the greater universe. Similarly, suitable scales for distance, motion, and time have had to be formulated and adapted to the use intended. Mathematical notation is of great service to the scientist for dealing with the vast relative differences in these scales.

Man often makes effective use of models of his own devising to symbolize the observed or deduced relativities of time, position, size, and motion. Models, such as a molecular model or a planetarium, aid the scientist in visualizing his own ideas and enable him to communicate his ideas and insights to others. He should however recognize limitations in his models, and that they are only models.

DISSIMILARITY AND DIVERSITY ARE NORMAL QUALITIES IN NATURAL PHENOMENA

No two things or events in this world are exactly alike; hence, diversity is normal -- that is to say, "It is normal to be different."

In the midst of such diversity, man searches for common characteristics and for order among these differences. This has led to systems of classification (the taxonomy of plants and animals, the periodic table of the elements, the electromagnetic spectrum) which are arbitrary concepts, invented by man and existing only in his own mind; yet these devices are of great value to man in his continued attempts to organize knowledge and in his efforts to modify and control his environment.

For anyone to accept these classification systems as absolute and immutable, would be a grave mistake, violating the purpose for which they were devised in the first place.

CHANGE IS A NORMAL CONDITION IN THE DYNAMIC CONTINUITY IN NATURE

Things and processes tend to continue in time, but are subject to change. This principle is particularly evident among living things. The normality of change must be accepted by man and made a part of man's outlook toward himself and his environment.

Nothing in the universe can be considered to be stationary and static, that is, unchanging. Change may be continuously developmental (evolutionary), or it may be recurring (cyclical) in its form. Even the "TRUTHS" man sees in nature are subject to change: old theories give way to better theories as new and broader knowledge forces a change in our view of older knowledge. Although some may appear to be capricious, all changes have their causes. The processes of change will continue.

NATURAL LAWS ARE UNIVERSAL, DEMONSTRABLE THROUGHOUT TIME AND SPACE

Time and space seem to have no definable limits. Yet man assumes that the natural laws which are observable today have been applicable at all times in the past, and will apply similarly in the future. He also assumes that these laws are valid in all parts of the universe; he assumes that when properly formulated, these laws will apply equally well regardless of the minuteness or the magnitude of the forces, motions, distances, sizes and durations of the things and events involved. Man recognizes, however, that as his knowledge is extended into new regions, he must test these assumptions anew; he must be prepared to modify ideas once regarded as fully tested.

Man has developed the concepts of time and space in terms of his own observations. Consequently his ideas are delimited to the extent that his mind and his senses are inadequate to grasp, discriminate, and comprehend the realities of the world around him.

Man must accordingly assume that as his knowledge of the physical world increases, both in depth of detail and in scope, these natural laws (which after all exist only as generalized observations, products of the mind of man) will need to be altered and amended in the light of increased knowledge. In other words, the natural laws as they are now expressed must not be looked upon as absolute or complete representations of the truth.

INTERDEPENDENCE AND INTERACTION WITH ENVIRONMENT ARE UNIVERSAL RELATIONSHIPS IN NATURE

Nothing in the universe exists in complete isolation. Even the limitless expanses of outer space are swept by solar winds and lapped by merging fields of gravity and magnetism. The most distant galaxies have broadcasted radio waves which are now reaching us, giving evidence of events long since "left behind" in time.

Everything in the universe, from the tiniest sub-atomic particles to the gigantic galaxies of outer space, exists in an environment which interacts with it. Every force, every particle or body, every event, is *what it is* partly because of what is interacting with it at the moment or in times past.

For anything to continue as it is, to function in its normal capacity and role, it must continue to interact with and be affected by the normal set of environmental factors. An interdependence is thus established which governs the course of events, the reactions, the very existence of the relationship. Scientific language itself reflects this universal relationship -- chemical *reactions*; *resolutions* of forces; *concentration* of solutions; temperature-pressure-volume *relations* in gases; food *chains*; carbon, nitrogen or water *cycles*; and *diastrophism*, to mention but a few.

FIELDS OF INFLUENCE EXTEND BEYOND THE VICINITY OF THEIR ORIGIN

Certain effects result from influences originating beyond the normal confines (physical boundaries) usually associated with their causes. The very presence of such a factor in the environment, without any discernible contacts or connections, may exert an influence. The strength of such influence usually varies inversely with some power of the distance from its source.

The concept of *fields of influence* may be exemplified in many ways -- through electrical, magnetic, and gravitational fields; through solar radiations, heat, light, and other energy fields; through presence of a teacher in the classroom, the Seventh Fleet off the coast, or an officer of the law on the beat; in an advancing storm center; or even in the precedences established by prior events.

EQUILIBRIUM IS A CONDITION TOWARD WHICH ALL SYSTEMS IN THE UNIVERSE TEND TO EVOLVE

Equilibrium is a condition where the net sum of all forces, motions, fields, and/or processes is zero or is apparently unchanging.

A system can be in *static* equilibrium -- as in a rock sitting on a hill -- where nothing, at least to the casual observer, is happening. Much more often, however, systems are in *dynamic* equilibrium, where opposing processes continue but counterbalance each other. Such is the case where molecules enter and leave a saturated atmosphere above a liquid at the same rate -- or where the total energy radiated from the Earth equals the energy that is absorbed by it.

The nature of the universe seems to be such that all systems tend toward equilibrium, perhaps in microseconds, perhaps in eons. Indeed, the very evolution of a system toward equilibrium constitutes in itself a variety of equilibrium.

The phenomenon of equilibrium exists not only in relatively simple physical systems, but also in complicated ones, physical and biological. It occurs in geological processes, ecological communities, evolution of stars, and the digestion of apple pie.

The evolution of a system toward equilibrium involves a lowering of its energy level. While this does not destroy energy, it makes it increasingly unavailable. That is, the entropy (the non-available energy) of any relatively isolated system inevitably increases and tends toward a maximum.

ENERGY INTERCHANGES ACCOMPANY EVERY NATURAL OCCURRENCE

Interchanges of energy are omnipresent and universal. Indeed, any change in the motion, physical state, temperature, or general behavior of matter is produced by, or at least accompanied by, energy change.

One common form of energy is kinetic — the energy of motion. A change of motion, whether it be an increase or decrease, requires the exertion of a force through a distance. Energy is also involved in heat and temperature, the propagation of sound and light, electrical and magnetic phenomena, chemical changes, geological gradation and diastrophism, the panorama of the weather, the radiation of the stars, and the evolution of galaxies.

The processes of biological growth require a continuous intake of energy. By the analysis of energy interchanges, a valuable clue is provided to the understanding of life.

MATTER IS PARTICULATE IN NATURE

At the sub-microscopic level, matter is composed of molecules (which are sometimes simply atoms). In a compound or element, all the molecules are essentially alike; but a mixture, made up of two or more components (elements or compounds), contains two or more different kinds of molecules. Molecules are frequently fractionated into electrically charged particles called ions.

According to the kinetic-molecular theory, molecules are in constant motion. In solids, they are tightly bound to each other and vibrate about fixed points. In liquids, molecules are less securely bound to each other and move about in close contact with each other. In gases, the intermolecular bonds are negligible, and molecular motion is large, free, and random. The temperature of a substance is proportional to the average kinetic energy of its particles.

At the sub-atomic level, matter is composed of fundamental particles. Most simple chemical and nuclear phenomena are explained in terms of protons, electrons, and neutrons. In addition, more than 30 other sub-atomic particles have been identified, although their role and their interrelationships are not yet completely known. It is to be expected that present ideas about the nature of matter will change as new experiments lead to new knowledge.

MATTER AND ENERGY ARE MANIFESTATIONS OF A SINGLE ENTITY, EVERLASTING AND INDESTRUCTIBLE

Recognition of the various forms of matter and energy and their transformation, and of the constancy of the matter-energy content in a closed system constitutes one of the great principles of scientific thinking.

Matter and energy are evidently two forms or manifestations of a single entity, matter being a highly concentrated form of energy -- a relationship best expressed in Einstein's equation, $E = mc^2$. In nuclear transformations, as in an atomic reactor or the sun, the magnitude of the energy released staggers the imagination. In ordinary chemical changes, which involve electron transfer, the energy change is comparatively small and the increase or decrease of matter is minute. Neither matter nor energy can be created or destroyed, but under certain circumstances and conditions, one may be converted into the other. It is believed that the total matter-energy content of the universe remains constant.

ENERGY CAN BE TRANSMITTED IN A VARIETY OF FORMS AND MANNERS

One important way by which energy is transferred or transmitted from one place to another is by the propagation of waves (i.e., fluctuations in an energy field). Wave forms may be changed in amplitude and frequence, or otherwise modulated to serve specific purposes in man's use of them.

Energy may also be transported in the form of moving particles of matter, as in a thrown brick, or an electric current -- even as photons. Energy may be propagated through fields of influence, as in the case of electrostatic or electromagnetic fields.

LIVING ORGANISMS ARE HIGHLY SPECIALIZED SYSTEMS OF MATTER AND ENERGY

Life represents a special system or organization of matter and energy. For life processes to continue once the system has become operational, a continuous input of energy is necessary.

The interaction of living organisms with their environment is continuous. Living things literally feed on their environment; they grow and reproduce themselves by making some portions of their environment a part of their own living bodies. This sort of growth is distinctly different from and vastly more complicated than the growth of a crystal, a snowball, or a cloud.

Living things have the ability to reproduce themselves. Like tends to beget like, the characteristics of parent organisms being duplicated for the most part in their offspring. However, as yet unpredictable but inevitable mutations are constantly occurring, introducing variations in the chain of life which may or may not be of benefit to subsequent generations. The mutation which most distinctly benefits an organism enhances its chances of survival, an advantage which it may pass on to its offspring. This is the basis for the belief that these hereditary changes tend to produce ever more complex structures with specialized functions, evolving further varieties in the forms of life.

Man is himself an animal, one of the most highly developed forms of living things. Because of his superior brain, he thinks far better than any other animal, and consequently can deal with his natural environment and adapt it to his needs. In fact, he can even consciously adapt himself to many of the changing aspects of the environments he must face. Because of his superior brain, man has invented art forms, work-saving machines, social organizations, complicated systems of communication, and health-giving as well as death-dealing devices. In fact, science has given man the means to destroy much of the life upon this earth, including himself, or to foster and safeguard it.

THE SCIENTIFIC ENTERPRISE HAS AT LEAST TWO FACETS: THE PROCESS AND THE PRODUCT

It appears that in the scientific enterprise, the process of science may hold greater promise for the solution of mankind's problems than do the products of science.

The product of science is knowledge, painstakingly accumulated and organized into meaningful generalizations, principles, laws, theories, and conceptual schemes. This knowledge is the end result of man's intellectual quest for deeper understandings of his natural environment -- for answers to his questions and the satisfaction of his curiosities. Through its product, science has had notable impact upon man's intellectual point of view and his material well-being in recent years; its influence is continuing to mount at an exponential rate, both directly and through technological progress.

The knowledge which science produces is finding extensive application and use in modern technology. It should be pointed out, however, that it is our technology, not science alone, which has led to the burgeoning production of synthetic plastics and wonder drugs, orbiting space vehicles and rocket planes, electric tooth brushes and wave-stabilizing hairsprays, and numerous gadgets, with profound effect upon our economic fortunes and our standards of living.

If man is to continue to profit from the scientific knowledge that he has amassed thus far, if he is to turn the full power of the scientific enterprise toward the solution of his own problems, he must consciously think scientifically about the things and events with which he must deal. The PROCESS of science must become as important in his mind and in his way of life as the PRODUCTS of science and technology!

The process of science is not a specific procedure for solving a scientific problem, slavishly followed step by step. It is not necessarily something which happens in a scientific laboratory or research facility, or in a library. The process of science is what happens in an individual's mind as he pursues his search for knowledge. To be scientific, his mental processes must meet certain standards of integrity and self-discipline — that is, they must evince the attitudes of mind characteristic of those who habitually make their decisions and draw their conclusions on the basis of the best evidence available.

The scientific attitudes of mind include such mental characteristics as these:

- Sincere curiosity to trace out cause-and-effect relationships
- Respect for the opinions and points-of-view of others
- Entertainment of honest and reasonable doubt in accepting dogmatic or unsupported statements of fact, or of personal beliefs
- Determination to be both clear-eyed and clear-headed (that is, objective) in observations, insofar as the observer can ever detach himself from the phenomenon observed
- Evaluation of evidence for its adequacy and reliability, and suspension of judgment when reliable evidence cannot be obtained
- Holding of any conclusion as tentative (since interpretations advanced today may be corrected and improved by new knowledge tomorrow), and changing one's ideas in the light of new evidence
- Rejection of superstitions, prejudices, mysticism or magic, animism, and anthropomorphism as bases for explaining natural phenomena
- Checking of the work of others before giving full credence to their results, and of one's own work in the same spirit
- Reluctance to rely upon a single or only a few observations of a phenomenon in seeking the evidence needed

Certain elements of method are common to various techniques by which scientists have been most successful in solving problems. There is no single step-by-step procedure that must be followed in attacking a problem scientifically. On the contrary, it is the SPIRIT that counts -- the carefulness, the honesty, the thoroughness with which the investigator seeks out the facts, checks them, and draws his conclusions.

The following elements of scientific method are usually observable in the procedures by which a scientist goes about his task; they are characteristic of the well-tested techniques of inquiry by which scientific knowledge has grown:

- Recognizing and clarifying the problem
- Gathering available information which seems appropriate and pertinent to the solution of the problem
- Setting up hypotheses and testing them experimentally, if possible
- Isolating the experimental factor by means of a control, when appropriate
- Running check experiments to verify findings
- Making careful measurements if feasible, to establish quantitative relationships
- Organizing the data in appropriate form, and interpreting them
- Drawing justifiable conclusions (suitably qualifying them if need be)

THE USE OF CONCEPTUAL THEMES IN CURRICULUM DEVELOPMENT AND IN TEACHING

As has been pointed out earlier, these major conceptual themes are among the "big ideas" underlying all science disciplines. They represent some of the common ground in concepts shared by the sciences, the universalities which pervade and integrate the whole field.

Every science teacher, regardless of the science discipline in which he specializes, should stress conceptual themes in his teaching. To the student who passes through a sequence of science courses in high school, studying under a different teacher's guidance at each level, these and other "strands" should impinge upon his consciousness like the recurring themes of a symphony, allowing him to recognize the same idea repeatedly in varying contexts. This experience should reinforce his earlier conceptions with fresh insights and depths of meaning.

These themes most emphatically should not be "taught" as specific units of subject matter with a block of time devoted to each, with all the ramifications of recitations and assignments, tests and reports, and the other exercises associated with topical treatment of subject matter. Instead, they should be built up quite subtly (yet deliberately) by the teacher in the context of whatever course content is being studied. They should appear as points-of-emphasis in passing, rather than as discrete topics.

- Curriculum workers (teachers, supervisors, audio-visual specialists, and others) may use such conceptual themes as part of the criteria in terms of which they evaluate and select textbooks. When writing a district course of study in science, curriculum workers will be in a position to build these recurring themes into the science courses and balance them in proper relationships to the other subject matter included. In test-construction, the teacher may consistently return to these themes time after time to check the growing comprehension and appreciation of the students for the "big ideas" involved.

Chapter III

THE PLACE OF SCIENCE IN THE HIGH SCHOOL CURRICULUM

A quality program of science instruction provides at each educational level the formal opportunity for students to expand their knowledge of science to the full extent of their abilities and desires. The relevant courses offered in the high school involve many problems that are best understood when viewed in terms of the philosophy upon which the science program is built, the objectives established for the program, and the prevailing trends in the field of science instruction.

SCIENCE AND THE SECONDARY SCHOOL CURRICULUM

Science has always been included in the curriculum of the American comprehensive high school. Its emphasis has generally been in the fields of biology, chemistry, and physics. The early courses were adaptations of college-level courses revised for high school students. They were maintained essentially for college-bound students.

Since the turn of the century the individuals of high school age attending school has risen from 11 to 90 percent. The resulting variation in ability and motivation of the pupils has created a need for the revision of courses formerly offered and the addition of other courses that provide students with the opportunity to complete high school and, when desired, to acquire limited vocational preparation. A high school education is now considered essential to employability and productivity in many walks of life.

In addition to science courses, the high school curriculum must include courses in the humanities, in the fine and practical arts, in foreign language, mathematics, English, physical education, and vocational education. All of these course offerings must be adapted to the varying abilities and interests of the students. They should permit each student to work to his capacity and to progress through his course of study toward graduation at a rate consistent with his ability, energy, and achievement.

Society cannot afford to let its citizens, and especially its potential leaders, mark time because the motivation, the learning opportunities, or the rate of progress do not provide an adequate challenge. In science education it has been found in this connection that valuable time can be saved by the introduction of more rigorous subject matter at earlier grade levels. At present, there is a trend toward offering more instruction in science in elementary and junior high schools. Formerly, it was only in the high schools that science instruction was given a position of importance. Up to the present time, course instruction has dealt primarily with known facts about science and too little with experimentation, generalization, application and the ways science develops. A complete review of the secondary school science program is needed to bring these elements into better balance.

An intelligent review of the curriculum must give consideration to: (1) maintenance of up-to-date curricula in science; (2) recruitment and training of competent teachers; and (3) use of the best in methods, materials, and equipment in science instruction.

THE SECONDARY SCHOOL CURRICULUM IN CALIFORNIA TODAY

The curriculum of the secondary schools of California today may be characterized as a patchwork of State mandates, of rules and regulations of the State Board of Education, of school district requirements, and of college entrance requirements. This is an uncoordinate result of change. Additional subjects are introduced, but seldom is a required course removed. Class schedules are then crowded and have little room for electives. Should legislated statutes adding science be recommended? No! Local school officials are overly burdened by present statutory requirements. Nevertheless, every student should have maximum opportunities for the study of the sciences. Then a basic minimum curriculum should be prescribed by the State Board of Education; this minimum curriculum, like all others, should be continuously evaluated and adjusted to meet the needs of the student and thus of society.

A FUNDAMENTAL PRINCIPLE IN CURRICULUM IMPROVEMENT

A primary belief regarding statewide curriculum improvement of any kind is that the State Board of Education should look first to the professional staff of the State Department of Education for advice, and then provide the necessary leadership in establishing minimum curriculum requirements.

Present legislative mandates plus college entrance requirements leave little room for electives for college-bound students in a six-period day until the junior or senior year. Graphic illustration of this situation is given in the chart, Figure III-1. There is time for electives for the student not bound for college, but the offerings in his behalf are very limited in most high schools. The daily program for the terminal-vocational student is apt to be filled with vocational courses, leaving no time at all for electives. These difficulties in the educational program of high schools merit careful consideration.

Figure III-1

Minimum State and University of California Requirements to be Completed by Students in Grades 7 Through 12 in California, as Scheduled in a Six-Period Day

(Placement of certain courses in Grades 9-12 is optional. Courses are shown in year where most frequently taken.)

7	8	9	10	11	12
Physical Education EC 8160	Physical Education EC 8160	Physical Education EC 8160	Physical Education EC 8160	Physical Education EC 8160	Physical Education EC 8160
English EC 7700	English EC 7700	English EC 7700	English EC 7700	English EC 7700	(Elective)
Social Science EC 7700	Social Science EC 7700	Social Science EC 7700	Driver Education (Part of semester) EC 8105(a)	Social Science EC 7700	Social Science EC 7700
Mathematics EC 7605 (elem.)	Mathematics EC 7605 (elem.)	Additional University of California Entrance Requirements Mathematics	Mathematics	Laboratory Science (one year) and One additional year of advanced Science, Mathematics or Language	
Foreign Language EC 7700 by AB375	Foreign Language EC 7700 by AB375	Foreign Language	Foreign Language	(Elective)	(Elective)
Natural Science EC 7604 (elem.)	Natural Science EC 7604 (elem.)	(Elective)	(Elective)	(Elective)	(Elective)

REMARKS

1. State Education Code Sections:
   EC 7700 specifies:
   English, five years
   Social science and history, five years including American, California and world history; American government; western civilization and world geography.
   EC 7604 and 7605 prescribe mathematics, language study and natural science and health as portions of specified larger blocks of time in the elementary schools "through grade 6 or 8, as the case may be." Requirements in junior high school are not clearly spelled out.
   EC 8105(a) requires that driver education be offered for a minimum of 30 hours. Some schools provide one semester. Approximately 2/3 of the schools give driver education in the tenth grade, and 1/3 in the ninth.
2. The University of California, in addition to two years of mathematics and two years of foreign language requires one year of a laboratory science in the junior or senior year. Usually chemistry or physics is selected.
3. In grades 7 and 8, six periods per day are required. In grades 9-12 five periods are usually required for the college-bound student. Local district requirements usually eliminate electives.
4. See Figure III-2 for possible sequences of science courses.

SEQUENCE OF SCIENCE COURSES

This report has emphasized the desirability of science instruction for all students, but not the same instruction for all. There will then be a variation in course sequence, in course content, and in the amount of science taken by different students. Every citizen completing grade 12 should have continuous science instruction (K-12), although it may not be possible for all to have it. Many different course-sequences will probably be needed in secondary school science. Each sequence presents some problems and each provides diversified opportunities. In the chart, Figure III-2, some possible sequences for various students are shown. Each is briefly analyzed in terms of the student and his capacity and objective, as well as in terms of the school that provides the instruction. Small schools must of necessity limit the diversity of their offerings; large high schools and specialized technical schools in large systems may have very advanced and experimental programs. Experimentation with a variety of sequences is recommended. There is special need to devise and to try new sequences for students who are not planning to go to college.

MINIMUM RECOMMENDED REQUIREMENTS

When determining what instruction should be required for every pupil in California, the State Board of Education with the advice of its professional staff should give consideration to these areas, and should prescribe a minimum of instruction in each:

English and related language arts
Foreign languages
Social sciences

Science
Mathematics
Health and physical education

Fine arts
Practical arts

The governing board of each district should then have the responsibility for providing instruction to satisfy these minimum standards, and the freedom to establish maximum standards of instruction to suit the needs of its student population. For students who probably will not continue their education beyond the public school, certain prevocational and vocational courses should be included in the curriculum.

In the field of science, the State Department of Education recommends, as an absolute minimum, that every student, during grades 7 through 12, devote not less than the equivalent of twenty semester periods to the comprehensive study of physical and life science. It is further recommended that the time be divided equally between the two branches of science with one-half the requirement to be completed after the student enters the tenth grade. It is also recommended that all students have the opportunity for experimentation, investigation, measurement, and interpretation of laboratory phenomena. Where present facilities limit the opportunity for individual laboratory experience, it is urgently recommended that school districts provide such facilities as soon as possible.

RECOMMENDED SCIENCE INSTRUCTION BEYOND MINIMUM REQUIREMENTS

Students who plan to continue their education at the college or university level should complete at least thirty semester periods of work in science. Two-thirds of this should be completed at or above the tenth grade. Students who will probably major in science in college or at a university and who plan to enter occupations or professions which require a science background should complete the equivalent of five years of science. All students, whether college-bound or not, should have the privilege of taking courses in science every year in secondary school.

ACHIEVING A QUALITY PROGRAM IN SCIENCE EDUCATION

Primary responsibility for the extent and quality of the educational program in the secondary schools rests with the individual school districts of California. Successes and failures which districts experience are contingent, to some extent, upon such factors as availability of competent teachers, financial resources, administrative leadership, and caliber of students. Governing boards of school districts do have considerable discretion, however, and with aggressive leadership and publicized school needs can overcome weaknesses and shortages. Communities that desire quality education can have it. Curricular requirements, physical facilities, instructional aids, grouping of pupils, scheduling of classes, teaching methods and innumerable other factors all have a bearing on the achievement of pupils. In order to assure the establishment of programs of high quality, the districts should look to the State Department of Education for suggestions. Information regarding prerequisites should be obtained from the colleges and universities which their graduates plan to attend.

Districts may be hard pressed to serve the special needs of high school students who are academically talented or who may be planning a career in science or an allied occupation. For such students, provision should be made for a longer school day, for special independent study and laboratory work. Advanced placement programs and the use of community resources, such as industrial and college laboratories and libraries, will aid and stimulate these students. The instructor who is assigned to work with these students should look upon himself as the organizer, motivator, and evaluator but not as the source of all information. Imagination and flexibility are of the essence for these talented students. A wealth of equipment and materials should be provided and, wherever possible, space

EXAMPLES OF POSSIBLE SEQUENCES OF SCIENCE COURSES

Notes:

1. In biology, chemistry, and physics the national programs—BSCS, CHEMS, CBA and PSSC—should be given consideration, however any standard high school course is acceptable. As new national programs develop, they should be considered.
2. In any particular school, any variation of course emphasis is possible; for example, a school may offer BSCS biology but traditional courses in chemistry and physics.
3. It is not expected that all students will register for six years of science. Most students will probably take two years of basic science, biology and chemistry or physics.
4. College-bound, nonscience majors will frequently take only one or two courses in senior high school.
5. Vocational, noncollege-bound students may only study science in grades 7 and 8 which is the minimum required by law in elementary schools. Others may elect technological science-related courses.

SEQUENCES	Grade 7	Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	ANALYSIS
I Accelerated	Science	Science	Biology	Chemistry	Physics	Advanced Courses Physics, Chemistry, Biology, or Earth and Space Science	Track I represents an accelerated program for superior students who plan to major in science and technology. This sequence is traditional but accelerated.
II Accelerated, Experimental	Science (Physical Emphasis; biological in 6th grade.)	Earth and Space Science	Biology	Chemistry	Physics	Advanced Courses and Individual Project-Work	Track II represents an experimental and accelerated program for superior students who are science majors.
III Experimental, College-Preparatory	Science (Biological Emphasis)	Science (Physical Emphasis)	Earth Science	Physics, $\frac{1}{2}$ year Biology, $\frac{1}{2}$ year	Chemistry	Physics and Molecular Biology	Track III presents an experimental approach to senior high school science. The track provides for presentation of some physics and chemistry before biology is completed. Suitable for general education and science majors.
IV Traditional, General Academic	Science (Unit or Block approach with conceptual themes developed. Includes earth science concepts.)	Science	Science	Biology	Chemistry	Physics	Track IV represents the traditional sequence with emphasis upon thematic development. Appropriate for all students. The basic science program is presented in units of subject matter that interrelate the disciplines.

Figure III-2 Suggested Sequences for a Six Year Science Program

SEQUENCES	Grade 7	Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	ANALYSIS
V Experimental Academic	Basic Science	Basic Science	Basic Science or Earth Science	Physics or Physical Science (Integrated two year course)	Chemistry	Biology	Track V follows the concept that physics is the most basic science. The greatest difficulty to this approach is that of providing mathematical background. Suitable for superior students in a large high school.
VI General Education	Science (Biological Emphasis)	Science (Physical Emphasis)	Science Principles and Techniques	Biology	Chemistry	Physics	Track VI represents the traditional sequence with ninth grade science designed to develop laboratory and mathematical skills. The ninth grade science may be considered as experimental. Suitable terminal program as well as a strong academic program.
VII General Education, Traditional	General Science	General Science	General Science	Biology	Chemistry	Physics	Track VII represents the traditional course sequence without special emphasis. All students may follow this program or any portions thereof.
VIII Terminal-Vocational	General Science	General Science	Laboratory Practice or Earth Science	Applied Science of a vocational type or Biology and Applied Science			Track VIII indicates a program suitable for development in special schools in large districts. The sequence is adapted to capable technology students or to slow learners. Careful programming and individual instruction indicated.
IX Extended Program	Natural History	General Science	General Science	Earth Science	Life Science (Modified BSCS)	Elective or Applied Science	Track IX provides an approach that may be suitable for slow learners. The student may be retarded and thus follow other programs but be one year behind his class.

Figure III-2 Suggested Sequences for a Six Year Science Program—Cont'd

for experimentation and exploration should be made available to outstanding students on a relatively permanent basis. This may require a different type of school plant than many schools now have. Consequently plans for remodeling or building new facilities should reflect the quality of education in science recommended in this report.

Graduation requirements are usually stated in terms of semester periods. Five semester periods of credit are usually given for meeting five days per week for one semester. There is nothing sacred about a class meeting five days a week. Scheduling of pupils should be flexible in nature and so planned that relatively long periods of time may be devoted to a single problem. The techniques of team teaching, coupled with flexible scheduling, may yield real benefits in the efficient use of teacher time and in student motivation and achievement. The extent and the manner in which this is accomplished will, of necessity, depend upon the community, the school staff, the financial support, the facilities and the maturity and interest of the student himself. For this reason, the state should provide leadership and resources, and should set minimum curricular standards. Beyond this the communities of California with the help of their educators should plan their own educational programs to fit their particular needs.

Again, it may be said that improvement in curriculum and instruction cannot be legislated. It can come about only through the leadership and cooperation of informed and dedicated teachers and administrators, and with the support of an interested citizenry ready to provide adequate financial support.

Chapter IV

MAJOR ASPECTS OF SCIENCE EDUCATION

All education is for the benefit of the student. The objectives of the science courses taught in the secondary schools should be established to meet student needs. This outlook pervades the following considerations of the general aspects of science education. Preceding chapters dealt with (1) general trends and objectives, (2) the use of themes to interrelate the total field of scientific knowledge, and (3) the problem of establishing a place in the curriculum for science. Later chapters deal with (1) the specific science courses currently offered, (2) effective nationwide programs of science instruction, and (3) detailed conclusions and recommendations.

The students in the secondary school vary widely in their aptitudes, abilities, backgrounds, and interests. Furthermore, the nature and effectiveness of in-school and of out-of-school experiences differ considerably for individuals and groups, with the result that individual differences continue to increase. This wide variation in accumulated experience and knowledge is very noticeable at the secondary school level and impinges markedly upon the program of science instruction.

Science instruction in the high school should provide for both general and special education in the sciences. By general education is meant those parts of the science curriculum developed specifically for the full range of students of high school age. By special education is meant those parts of the science curriculum developed for special groups such as the slow learners, the college preparatory, and the science majors. Programs in science instruction should provide for these identifiable groups. The most common practice in the schools of California, however, is to provide a college preparatory sequence of science courses, and these are usually oriented toward the science major. Some authorities believe that curricula should provide also for (1) the college-preparatory nonscience major, (2) the terminal student with interest in science, and (3) the terminal student who does not have much interest in science. In Chapter III, Figure III-2 shows alternate acceptable sequences of science courses for students in these categories. The general methods and objectives are comparable, however, for all of the science courses.

The National Science Teachers Association takes the position that, to be fully adequate, the school science program:

1. Must be articulated from one level to the next through grade twelve or higher;
2. Must encompass a full range of the contemporary knowledge and ideas which scientists employ;

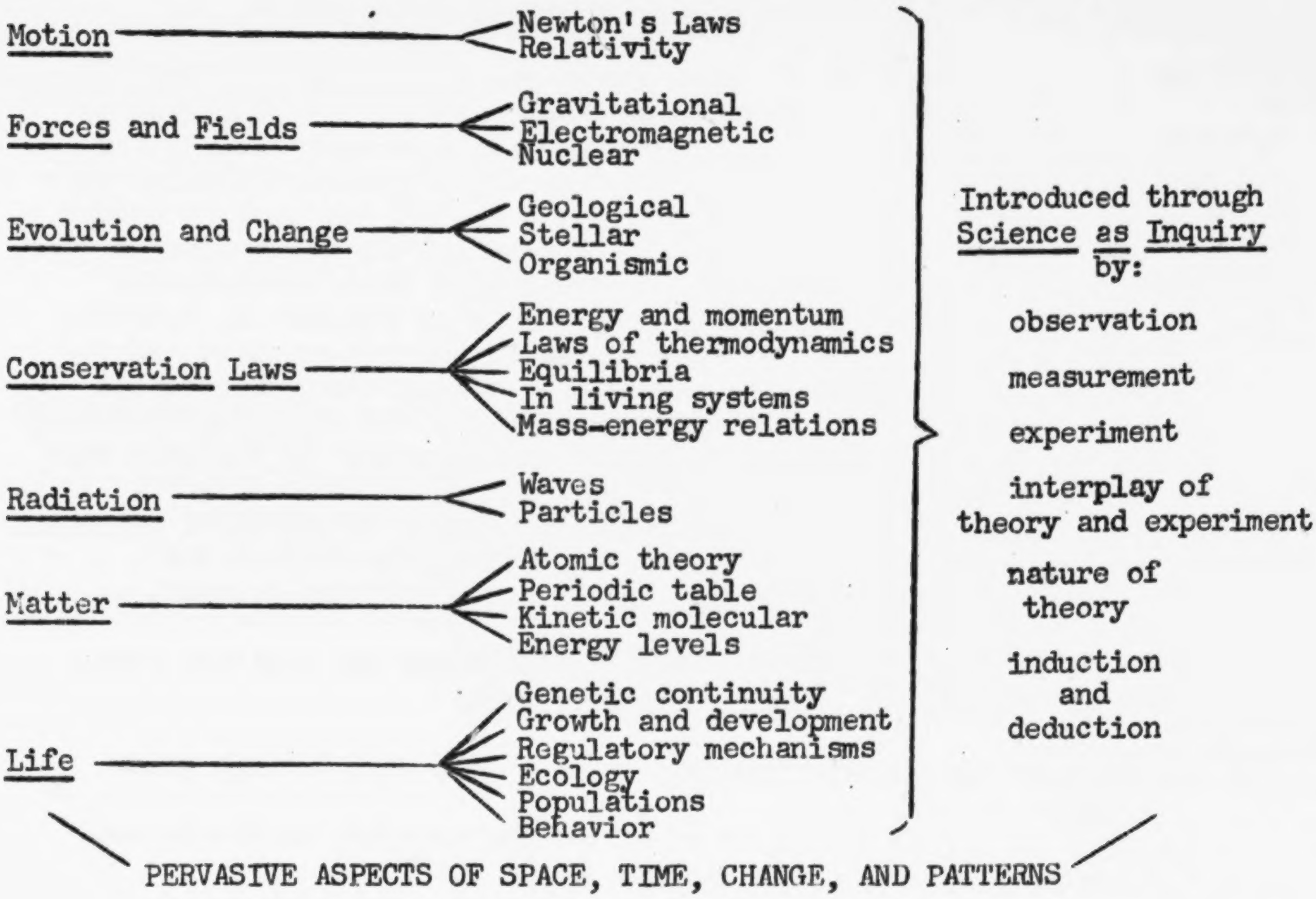
3. Must result in understanding the nature of the scientific enterprise through direct student involvement in the processes of scientific inquiry;
4. Must involve the best that is known about child growth and development and the psychology of learning; and
5. Must be supported by first-rate staff, facilities, and instructional materials.

Certain general aspects of science education are applicable to all of the separate science courses taught in the secondary schools. Each course, within its scope, contributes to the acquisition of knowledge and to the development of specific skills and attitudes that are the objectives of such education. Success in the instructional program in science is dependent to a great extent upon laboratory experience.

KEY IDEAS FOR SCIENCE IN GENERAL EDUCATION

From the areas of physics, chemistry, biology, earth science, and junior high school science, there has been selected a condensed list of key ideas. No single discipline will cover all of the key ideas, however, teachers should constantly seek to present interrelationships.

Figure IV-1. Key Ideas for General Education Science


Motion
Newton's Laws
Relativity
Forces and Fields
Gravitational
Electromagnetic
Nuclear
Evolution and Change
Geological
Stellar
Organismic
Conservation Laws
Energy and momentum
Laws of thermodynamics
Equilibria
In living systems
Mass-energy relations
Radiation
Waves
Particles
Matter
Atomic theory
Periodic table
Kinetic molecular
Energy levels
Life
Genetic continuity
Growth and development
Regulatory mechanisms
Ecology
Populations
Behavior
Introduced through Science as Inquiry by:
observation
measurement
experiment
interplay of theory and experiment
nature of theory
induction and deduction
PERVASIVE ASPECTS OF SPACE, TIME, CHANGE, AND PATTERNS

Consideration of conceptual themes, Chapter II, should aid in establishing the interrelationship of the key ideas that are summarized in Figure IV-1. An attempt has been made to condense the suggested key ideas into a pattern useful for general education science. Much must be done in further developing this pattern and in implementing it. Synthesis of such a pattern is an important first step toward more effective instruction for all secondary students in science.

In this greatly reduced list of fundamentals there are numerous cross-links and interconnections. Only a few of these are indicated. Emphasis, where possible, should be put upon interrelations for they frequently cross the boundaries of traditionally separate disciplines.

ATTITUDES TO BE DEVELOPED

- Challenge existing ideas. Science has made many contributions to man's ideas and attitudes. One of the great strengths of science lies in man's ability to formulate generalizations (rules and laws) out of many observations. Willingness to accept these rules and laws without questioning them, however, may be a deterrent to further scientific progress.

- Acknowledge the tentative nature of proof. Proof, as usually accepted, is based upon the accumulation of evidence. In scientific investigations the data accumulated may be thought to be complete but are not necessarily so. The answers are seldom final or absolute. Scientific investigations should be open ended. As such, they lead to further studies, a reflection of the self-correcting nature of scientific inquiry.

- Concede that alternate interpretations of data are often possible. The student should be urged to evaluate and to challenge the accepted interpretation. A spirit of disputatiousness should be encouraged. There often is no "one right answer" to a problem.

- Recognize that measurement, a prime tool of science, is subject to uncertainty. The accuracy that may be achieved is always limited by the physical devices that are used in collecting the data. It is incorrect to give answers to a degree greater than the least accurate measurement. For most measurements in high school science, accuracy to three significant figures is satisfactory.

- Realize that there is a difference between precision and accuracy. In an experiment the observer may obtain precise measurements (measurements which agree with one another time after time) but if the measuring technique or device is in error the result will not be accurate. The average of a statistically valid number of observations, though quite diverse in value, may be more accurate than that resulting from observations that are in close agreement with each other.

- Appreciate that models are only representations. Models-- of dinosaurs or of molecules--serve an exceedingly important function in science education. Models enable the teacher to convey the ideas more effectively to the student. They frequently serve as a basis for rationalization and prediction. It must be remembered, however, that models are man's creation. They are man's method of gaining a clearer image regarding what he thinks the thing is like.

The foregoing briefly-discussed ideas are examples of attitudes that the student should acquire as he pursues his study of science. The list can be increased extensively. Teachers, supervisors, and curriculum coordinators should constantly look for opportunities to develop such attitudes regarding the sciences studied. The following may be helpful in such a search.

ADDITIONAL IDEAS TO BE REITERATED IN HIGH SCHOOL SCIENCE TEACHING

- Science is dynamic, ever growing, and experimental,-- an unfinished human endeavor.
    - (a) Weave the history and the great names of science into each course.
    - (b) Search for "models of nature" and for changing concepts.
- Science deals with things concrete and definite, as well as with ideas.
- A creative approach is essential; innovation and discovery are self-rewarding.
- The interplay between theory and experiment is predictive. Use quantitative approaches whenever possible.
- A "moral code of science" places authority of experimental evidence over the authority of the individual.
- Science as inquiry encourages the habit of asking questions and seeking answers. Curiosity should be aroused but seldom completely satisfied.

SKILLS TO BE DEVELOPED

Every craftsman should develop skill in the use of the tools of his trade. The student of science needs both intellectual and mechanical skills. To develop them, he should:

- Use mathematical skills to the utmost. Whenever possible, formulas should be developed as needed, not memorized.

- Develop reasoning and analytical abilities.

- Know the language (the terminology) of the science.

- Make meaningful observations and measurements and record data.

- Learn to use the instruments required for the practice of the science.

- Recognize the importance of relationships and of their mathematical and graphical representation.

- Comprehend the units and dimensions involved.

- Devise and interpret visual representations of ideas.

- Know how to use the literature and other resources: textbooks, handbooks, reference books, scientific journals, charts.

- Gain as much knowledge as required regarding: the metric system, use of exponents and conversion factors, symbols, formulas, and equations.

These skills and the related knowledge should not be looked upon as the science studied; instead they should be considered as the tools that are essential in skillful manipulation of the procedures and the concepts of the science. Nor should these tools (such as symbols and formulas) be merely memorized; instead, they should be learned as needed by using them. Each course in any sequence should introduce the essential ideas; each should contribute to the courses that follow.

THE ROLE OF THE LABORATORY

In science education today, attention is being focused upon the laboratory. Science education is rapidly approaching the stage wherein the student in the laboratory will seldom perform an experiment merely to confirm information that he has learned from the text. Instead, laboratory experiments are now being structured so that the student seeks an answer to a problem. He will tackle the problem as the chemist, the physicist, or the biologist would. Most appropriately, laboratory observations will precede the use of text materials. Many of the experiments will be of an investigative nature. The results obtained may not always be correct, but they should lead to the formulation of hypotheses that will lead to further investigation and finally to conclusions.

With this as the role of the laboratory and with problems adjusted to the level of the course work, new vistas can open for both the student and the teacher. Whenever possible, the emphasis will be upon individual work. Such laboratory work may lead to:

- Cultivating a spirit of investigation: seeking answers to questions through experiment
- Learning by doing -- an important way to learn the process of science
- Establishing direct contact with nature -- and understanding natural laws
- Improving habits of observation and imagination
- Making significant measurements, then reasoning "in depth" to interpret results
- Having regard for errors in measurement
- Noting the value of discrepancies
- Appreciating the authority of experiment
- Applying previous learning to new and practical situations
- Devising experimental techniques and apparatus.

The word "laboratory" suggests different ideas to different persons. It is here intended to include (but not be limited by) a place equipped with suitable materials and instruments of measurement where students may perform individual (or small team) experiments of an investigative nature. In many instances such observations may be made in the field or at home -- the important thing is that the student shall have personal experience. Science instruction should consist of an integrated pattern of learning experiences in which, at all times, individual laboratory work is a central part. The habits of inquiry and the development of competence in the processes of investigation through field and laboratory work may generate interests and capabilities for a personal, life-long quest for knowledge.

The necessity for laboratory investigation does not lie only with its unique experimental contribution. Laboratory experimentation and observation of natural phenomena are an integral part of the scientific way of discovering and of knowing. Inquiry in the field and in the laboratory should involve the student in discovering facts and ideas new to him. Laboratory problems which only illustrate what is already known to the student have limited value although the repetition of historical experiments may be effectively used to assist the student in understanding the difficulties of extracting data from nature and certainly individual and small group laboratory work must be an integral part of the general education curriculum. The experience should have for the student the same primary value it offers the scientist as a method of finding answers to fundamental questions.

The class-experiment and demonstration-experiment also fill an important place. Many such experiments can be made quantitative. As an adjunct to individual contact with equipment, they are valuable, but they should not be allowed to substitute for individual laboratory experience.

IMPLEMENTING THE LABORATORY PROGRAM

The type of work described on the preceding pages requires time and space and material. The effective development of adequate laboratory programs will have far-reaching effects upon building design, facilities, equipment and supplies, class schedules and class sizes. Needless to say, all of these will create administrative problems and will strain school budgets.

Equipment and materials of adequate quality must be furnished in sufficient quantity to meet the needs of the changing emphases in science instruction. Schools should encourage innovation. Especially designed facilities can make possible (1) the variation and individualization of laboratory experiments, (2) the encouragement of individual study and creative thinking, (3) wide use of various instructional techniques, and (4) adaptation of many experiments to cooperative group investigation.

Continuing changes in the content, approach and techniques of science instruction require that buildings, facilities, equipment and furniture be designed for maximum flexibility of use. Costs of operation and maintenance and of easy modification are important factors to be considered in planning. The design of classroom-laboratories and special rooms needed for the various activities of the science program should be based on the functions to be served. The teachers, supervisors and administrators concerned should make the immediate and long-range functional needs clear to the architect who designs the facilities. Each science course requires specialized movable equipment and storage space for it.

- The combination classroom-laboratory arrangement is most suitable for all science courses.

- All science rooms should be amply provided with gas, water and and electirc outlets.

- The design of the room should be specific for the subject taught.

- For junior high school classes, the classroom-laboratory should be as flexible as possible to provide for the changing activities that will take place. Movable tables are desirable.

- The optimum arrangement should have twenty-four student stations.

- Adequate storage space must be provided. Some supplies and equipment need to be kept in locked rooms.

- A "project room" for long-term experiments, preparation, special equipment, and advanced science assignments is desirable.

Facilities and Equipment

The facilities provided and the equipment purchased should be specified so as to effectively implement the teaching of the desirable concepts; the content of the science course should not be built around the equipment. The experienced science teacher may adapt his work, but careful planning in advance is preferable.

- Teachers should requisition only such equipment as will be needed to develop given principles and concepts.

- Elaborate and expensive instruments are frequently incomprehensible to students and therefore do not serve effectively for teaching. Equipment should not be judged on a basis of cost, sophistication or "black-box" quality.

- Supervisors and administrators should encourage teachers to explore and use surplus equipment.

- A reserve fund should be made available for the securing of equipment and supplies throughout the school year.

Scheduling

For the most effective teaching of science a number of innovations involving scheduling are noteworthy. Trends in science teaching favor:

- Flexible scheduling in such a manner, for example, as to provide for maximum integration of mathematics and science, for longer laboratory periods, and for field trips.

- The provision of two-hour laboratory periods in some courses.

- The opportunity for late afternoon and possibly for Saturday work in special cases.

- Team teaching arrangements.

- Limitation of class size to twenty-four students in order that individual laboratory work may be performed and may be adequately supervised.

THE TEACHER

The real crux in any science program is not the subject and its compression or expansion at particular points, but the quality and ability of the teacher. An unmotivated teacher will not motivate students. The course will be no more "intellectual" than he makes it. Highly qualified personnel, extensive counseling, assignments based upon teacher preparation and competencies, and favorable working conditions are all necessary for effective science teaching.

The supply of available, well-qualified science teachers is becoming more critical. It is not enough for teacher training institutions to be able to prepare good science teachers of those students who volunteer. Careful guidance on the part of college faculties is needed to encourage outstanding young men and women to enter science teaching. Candidates need to be identified early and counseled toward proper curricula. Too many good science teachers are transferring to industry and to college faculties; administrators should do all they can to keep their teachers.

The science teacher must remain a scholar during all of his career. No longer can the science teacher complete a four- or five-year college program and expect his training to be finished in his chosen academic field. Scientific knowledge has a high rate of obsolescence. Inservice training is particularly essential for maintaining teacher-effectiveness in the evolving science-programs. The programs of federal and state agencies such as NSF and NDEA, which are designed to upgrade and update the backgrounds of science teachers, have had a positive influence on science teaching. It is desirable that these programs be continued and expanded. Future programs of similar nature will require more cooperative planning on the part of school and university officials to identify and meet specific inservice needs.

The teacher, himself, has many obligations in connection with maintenance of continued professional competence. He should attend summer programs such as the NSF provides with the sincere desire to obtain new ideas and new knowledge. (The federally supported programs should not be considered as a paid vacation.) Furthermore, the truly professional teacher will participate actively in science organizations. Administrators and school boards should encourage such participation. An arrangement within each school system should make it possible for all teachers to attend professional improvement activities without loss of time or salary.

There must be freedom from excessive minor administrative assignments which are unrelated to science teaching. Preparation for laboratory classes requires considerable time and energy. This should be counted as a part of the teaching load. Laboratory courses should have assistants available, some of whom may be outstanding students who have completed the course. These young people will be of help and inspiration to their fellow students, and will become more competent themselves. Many may even resolve to become teachers as a result of such experience.

Chapter V

SECONDARY SCHOOL SCIENCE COURSES

The essential ideas of the various secondary school science courses and general guidelines for consideration of course content and effective teaching are discussed on the following pages. The intent is not to:

1. Provide a detailed course outline in any science.
2. Favor any new program of instruction or any so-called "traditional" presentation over another.
3. Prescribe a course sequence. Sample sequences are shown, however, in Figure III-2.

Major concepts are suggested. They are not listed in order of importance or as a preferred instructional sequence. The teacher may utilize them in adjusting his instruction to the materials and facilities available, and in terms of his own ideas of instruction.

Recognition of the interrelationship and interdependence of the several sciences is paramount. All teachers desire to build upon the foundation provided by previous science courses, and to prepare the student for subsequent courses. Thus, a basic science program at the junior high school level builds upon what has been learned earlier and also introduces concepts and factual background for the specialized disciplines taught in senior high school. If this articulation is effective, decisions regarding sequence and content of courses are simplified.

There is no ideal sequence of courses. For example, a stronger course in biology can be provided if students already possess an adequate background in the principles of chemistry and physics. Should biology, then, be a twelfth grade subject? If physics should precede chemistry and biology, as many recommend, is it possible for the student to have had sufficient mathematics to study physics effectively? Since chemistry, physics and mathematics are currently important in the study of earth science, should earth science be a twelfth grade subject? These questions can never be answered satisfactorily to everyone and their very existence makes difficult the choice of an acceptable program for junior high schools. Furthermore, this choice is made more critical because only a very small percent of the total student body will elect the six years of science considered desirable for secondary school curricula.

Progress in science education is already apparent. More information and many ideas designed to stimulate thought are being introduced in grades K-6. In some junior high school science courses, some fundamental principles of chemistry and physics are introduced. Inquiry is encouraged. In some senior high schools, advanced science courses or honors programs are being offered in the twelfth year. These trends indicate that young people are being prepared for more rigorous work at an earlier age.

Some fear that these trends in science education are demanding too much maturity of the child. Others point with enthusiasm to the fact that children today are able to do the work. There may well be a concomitant revival of cultural values. Certainly, there is more challenge provided for the capable student; careful programming and special courses may be required to serve the needs of the less capable. In general, however, a modern approach to science instruction is best for all students.

Many common aspects of current development and improvement in science instruction in the secondary schools were discussed in the preceding chapter. At this point the courses themselves are considered individually for the purpose of identifying, in outline form, the concepts that are basic to each course. Trends and ideas unique to specific courses are indicated.

A. COURSES IN THE SENIOR AND FOUR-YEAR HIGH SCHOOL PROGRAM

PHYSICS

Physics is perhaps the most basic of all the sciences. Key words that physics seems to encompass are: Matter, Motion, Forces, Fields, Energy, Momentum, Radiation, Waves, Atoms, Entropy, and Time.

In addition to acquiring an understanding of the unifying concepts of physics, the student should develop tool skills and useful attitudes. The primary objective for the study of physics, however, is the acquisition of knowledge about the subject matter of the science and the development of ability to understand and to apply this knowledge. These outgrowths are both cultural and vocational. The vocational uses may represent the direct use of the knowledge per se, or the use of knowledge in support of further study. The cultural values are found in a more profound understanding and appreciation of our world and our civilization.

TRENDS

- Unifying strands of significance to modern physics are selected. This results in the elimination of the compartmentalization which has long been typical of traditional physics courses.

- Attention to both mathematical and philosophical treatment of topics has been increased.

- Many new devices are available for use in the laboratory. Some of these devices are ingenious; most of them stress measurement and the interpretation of data.

- There is an increasing tendency to introduce only sufficient technical applications to enrich the course and to motivate the students.

BASIC OUTLINE

The course in high school physics should include the presentation of ideas and data regarding the following fundamental topics.

- I. Conservation Laws
    - A. Mass-Energy
    - B. Momentum: - Linear and Angular
    - C. Charge, Particles
- II. Motion--Time--Space
    - A. Statics: - Principles of Equilibrium
    - B. Kinematics: - Velocity, Acceleration
    - C. Dynamics: - Forces and Torques; Laws of Motion
    - D. Special Relativity; Frames of Reference
- III. Gravitation, Law of
    - A. Historic Impact and Development of Thought: Newton, Kepler, etc.
    - B. Dynamics of Circular Motion
- IV. Waves and Propagation of Energy
    - A. Simple Harmonic Motion
    - B. Water, Sound, Light, Electromagnetic Waves
    - C. Wave-Particle Dualism
- V. Physical Optics
    - A. Reflection, Refraction, Dispersion, Interference
    - B. Spectra
- VI. Kinetic Theory
    - A. Gas Pressure and Kinetics
    - B. Heat and Work
    - C. Statistical Interpretation: - Temperature and Heat
- VII. Fields--Interactions
    - A. Gravitation (relate to III)
    - B. Electric and Magnetic
        - 1. Coulomb's Law
        - 2. Electric Circuits
        - 3. Faraday's Electromagnetic Induction
    - C. Idea of Potential Energy
        - 1. Gravitational
        - 2. Electrical
        - 3. Elastic
- VIII. Atomic Concepts
    - A. Atoms and Electrons
    - B. Energy Levels, Quantum Ideas
    - C. Nuclei, Elementary Particles
        - 1. Strong and Weak Interactions, Nuclear Forces
        - 2. Particle Accelerators
        - 3. Radioactivity, Fission, Fusion

The concepts related to the foregoing topics are fundamental to an understanding of physics. There should be no attempt to create one skeleton for general education, another for college-bound students, and yet another for science majors. The same ideas and principles should be covered in all physics courses. The teacher of physics, however, should carefully plan his presentation; he should display his skill by matching the level of instruction to the needs and capabilities of his students. In general, the course entitled physics should be more analytical and mathematical than descriptive. This idea encourages the placement of physics during the latter part of the high school's program by which time students will have had more opportunity to study mathematics.

CHEMISTRY

An understanding of chemical principles and a knowledge of facts about chemistry are fundamentals to success in many vocations. For the majority of students, chemistry is a supporting science -- a tool to be used in attaining a better understanding of other courses. Knowledge of chemistry also contributes richly to an appreciation and evaluation of the materials, the events, and the news of the day. Although knowledge of chemistry is valuable to all citizens, it does not follow that the same depth of understanding should (or can) be required of all students. Accordingly, the specific course entitled chemistry should be considered as the academic course. Some broad-field science courses should include the basic concepts of chemistry with the incorporation of many ideas from physics. In such courses the emphasis and the depth of coverage would be different from the outline here presented. In applied science courses the trends are similar even though the technological outcomes of chemistry (and of physics), in these special courses, receive greater attention.

TRENDS

- Atomic structure is being introduced early in the course. Properties of the elements and their compounds are being related to structure.
- Key ideas or themes frequently used for the unification of subject matter are: structure and energy; the chemical bond; periodicity; equilibria.
- There is a reduction in specifically structured experiments. Thus, in the laboratory the inquiry approach is stressed.
- There is an increased dependence upon higher mathematics as a tool of chemistry.

- The use of double laboratory periods is encouraged, and, in a f schools, the time allotted to the chemistry course has been increased to seven periods per week.

- Chemistry is being recognized more and more as a primary tool or supporting science for all other sciences and for many vocations.

- The great increase in knowledge and publicity about organic an biochemical materials and about radioactivity have made thes areas source of intensely interesting to students.

It is significant to note that enrollment in chemistry is increas throughout the nation. One implication is the placing of a much great responsibility upon the preceding science and mathematics courses to p vide a proper foundation for chemistry.

BASIC CONCEPTS

Following is a guiding list of essential ideas and concepts, in no special order, that should be covered in the high school course in chemistry.

I. The Chemical Bond
    Atomic and molecular structure
    Coulombic forces
    Effect of charge distribution
    Bond breaking and forming -- mechanism of reaction
II. Periodicity
    Systematic, descriptive chemistry
    Ionization potential
    Electronegativity
    Physical properties
    Chemical properties
III. Kinetic Molecular Theory
    Boltzmann curves of energy distribution
    The gas laws -- developed by reasoning
IV. Kinetics (factors affecting reaction rate)
    Effect of temperature (Boltzmann energy distribution graphs)
    Effect of concentration
    Mechanism of chemical change
    Effect of slowest step in a sequence of chemical reactions
V. Energetics
    Energy changes -- during reaction or phase changes
    Energy barriers -- activation energy curves
    Role of catalysts

VI. Dynamic Equilibria
  - Acid-base
  - Oxidation-reduction
  - Solubility (molarity seems sufficient as a unit of concentration)
  - Ionization
  - LeChatelier's principle
  - Energy and randomness

VII. Conservation Laws
  - Atoms, charge, mass, energy
  - The mole as a unit of quantity (1 mole = 6×10^{23} particles)
  - Balancing equations

VIII. Atomic and Molecular Theory
  - Structure of atoms
  - Structure of molecules
  - Structure of solids
    - Ionic crystals
    - Metal crystals
    - Covalent solids

IX. Systematic Chemistry
  - Study of selected chemical systems using experimental data and unifying concepts

X. Use of Isotopic Tracers
  - Dynamic equilibrium (solid and solution)
  - Medical diagnosis
  - Activation analysis

XI. Organic Compounds and Biochemical Relationships

E TOOLS OF CHEMISTRY

Certain skills and knowledge must be used in chemistry. These do
t constitute the science of chemistry; instead they are the tools
ssential to the skillful manipulation of the procedures and the con-
epts of chemistry. These tools (such as symbols and formulas) should
t be memorized; instead they should be learned, as needed, by using
em. The study of chemistry will proceed in an orderly fashion and
st rapidly if many of the ideas involved will have been introduced,
ough not necessarily mastered, at the junior high school level.

BIOLOGY

Biology encompasses such a tremendous area of knowledge -- living
ings and the factors that influence their existence -- that the
lection of subject matter for the high school course is quite arbitrary.
a result, there is justifiable lack of uniformity in biology courses.
ology occupies an important place in the science curriculum because
mans themselves are living beings and because the study of biology pro-
des the opportunity to integrate all the sciences. The all inclusiveness

of biology justifies it as the specific science discipline studied by the greatest number of students in high school. A major responsibility of the school and of the teacher is, thus, to provide an effective program in biology.

TRENDS

- Since the body of subject matter is so diverse, there is a trend toward the selection and use of some major theme or themes to give continuity and to establish interrelationships. The detailed classification and description of living things is now deemphasized as a basis of course organization.

- There is a pronounced tendency to introduce biochemical and biophysical treatment of subject matter. This trend presupposes an appropriate introduction of concepts of physics and chemistry in previous science courses.

- Quantitative treatment of biological data is increasing. Experimentation involving sustained and well-defined laboratory problems necessitating observation and interpretation of data is taking precedence.

- Biology remains primarily as a tenth grade subject, but more schools are offering a special course in biology as a twelfth grade subject following chemistry and physics. On the other hand, more schools are permitting qualified ninth grade students to register for biology.

The foregoing trends coupled with the tremendous amount of subject matter necessitate careful selection and organization of course content and methods. The following guidelines are in addition to the more general guidelines for science courses that are listed in Chapter IV.

GUIDELINES

- A diagrammatic representation of the diverse methods of organization of subject matter in biology is given in Figure VI-1.

- The subject matter content of science in grades seven, eight and nine should include some basic concepts of chemistry and physics and their application to living systems; if the background does not exist, time will be required to establish this background.

- Instruction in biology must emphasize the part that knowledge plays in scientific inquiry, and that inquiry plays in the development of scientific knowledge. The student should, whenever possible, be introduced to some of the frontiers of biological research.

- An underlying current of aesthetic appreciation for life and its processes should be established. The teacher of biology must never forget his responsibility to create in his students an awareness of the "natural" world in which they live.

- Biological instruction should provide the basis for understanding relationships of natural resources to the problems of human health and survival.

- The specific content in biology selected by the teacher should relate to the needs and interests of his students and the community.

- Historical anecdotes add impact, understanding, and interest to the lecture, demonstration, and laboratory work. Many of the classical experiments in biology are available as vivid examples of inquiry in action.

- The quantitative aspect of biology should be emphasized, particularly in the laboratory. Statistical support for data interpretation should be applied to experimental results where possible.

THEMES AND APPROACHES

Some of the major themes which should permeate any approach in the study of biology are:

- Variety and pattern of living organisms.

- Continuity and change emphasizing genetic continuity and regulation in living systems.

- Interaction and interdependence showing the relationship of the organism to its environment and the complementarity of organ and function.

- Evolutionary change through natural selection and through mutation caused by gene interaction with environment.

- Relation of biology to the student and his community.

These themes and the sequence of presentation of the diverse topics in biology may be expressed through levels of organization such as the following: Molecular, Cellular, Organisms and Populations, Physiological, Taxonomic, Ecological, Behavioristic, or Historic.

EARTH SCIENCE

In recent years there has been a rapidly expanding interest in natural phenomena directly related to planet earth. Earth science has become an appropriate course for interrelating earth-oriented concepts, much as biology became the frame of reference for the over-all study of living things a half century ago. Recognition of an earth-centered branch of science stems from the facts that:

- Phenomena of the earth, especially of its surface, interact with each other to produce the complex commonly known as the "natural environment." The interaction and the earth-centered nature of the phenomena provide unity for the discipline.
- Earth science provides a rational body of knowledge developed within this framework of interrelationships.
- In our resource-extravagant society with basic resources earth-centered, an understanding of the natural environment-complex is essential to proper evaluation and handling of our society's problems.

ESSENTIAL EARTH SCIENCE IDEAS

The body of knowledge that comprises earth science is not well known to many educators who are planning science curricula. Specific concepts are drawn from a wide field of sciences: geology, physical geography, meteorology, oceanography, agriculture, mineralogy, astro-physics, and paleontology. Biology, chemistry, physics, and mathematics are supporting sciences. The following topical identification may serve as a guide for ideas and concepts to be included in earth science.

1. Earth in space and related phenomena (day-night, seasons, receipt of solar energy, tides); this area, with astronomy concepts, can be expanded into "space science."
2. Heat balance on the earth's various surfaces (incoming solar energy vs. heat loss as influenced by land and water, altitude, latitude, and seasonal changes in the relationship of earth and sun)
3. Water vapor as a component of the atmosphere, considering:
   a. water vapor as a variable component in the mixture of gases that is air, and
   b. the hydrologic cycle and relationships involved in its various processes
4. Energy dynamics of the atmosphere, considering:
   a. heating of the atmosphere,
   b. operation of the gas laws in an atmosphere "contained" by its own weight,
   c. motions of air due to unequal heating of the earth's surface, and
   d. energy exchanges involved in the hydrologic cycle

5. Atmospheric and oceanic heat-equalizing circulations and their influence on the earth
6. Patterns of variation within the atmosphere, considering:
   a. the concept of "synoptic" patterns,
   b. the representation of patterns in two and three dimensions on maps,
   c. changing patterns of daily weather (cause and significance),
   d. air masses and fronts, and
   e. climate as recurring seasonal patterns of weather
7. Rocks of the earth's crust; their chemical composition and origin
8. Mobility of the earth's crust considering vertical and horizontal crustal movement and related rock structures
9. Shaping of the earth's land surface (tectonic construction vs. gradational leveling, and the typical landforms evolved)
10. Sea against land: the forces and processes shaping and positioning coastlines
11. Soil forming processes and soils so evolved
12. Interaction of earth-phenomena with life forms
13. Origin and evolution of planet earth (the evolving lithosphere, atmosphere, and biospheres; to include fossil study, evidences of climatic change, etc.)

LABORATORY EXPERIENCE

The study of earth science provides many opportunities for investigative experience of an observational nature. Due to the nature of the subject, the laboratory for investigation occurs both in the classroom and out-of-doors. Data gathered, though frequently less mathematical in nature than that of some other sciences, nevertheless supplies "meat" for inductive reasoning and discovery. Some examples of investigative activities appropriate to the study of earth science are:

Outdoors:
1. Observation and tabulation of selected occurrences of rock, soil, and vegetation. The student can discover interrelationship of earth elements from these data.
2. Collection and organization of rock and soil specimens for further study and analysis in the classroom and laboratory.
3. Collection of weather data as it actually occurs. From these data the student may inductively study and predict atmospheric phenomena.

Classroom:
1. Laboratory analysis by various techniques of lithic materials collected outdoors or made available by the instructor.
2. Interpretation of topographic maps with regard to land forms and earth shaping processes.
3. Study of weather maps as an aid to better understanding of air phenomena and the changing patterns in the atmosphere.

THEMATIC DEVELOPMENT

The grouping of certain natural phenomena into an earth-centered frame of reference in itself is thematic in nature and is one of the significant contributions of this area of science. Themes which pervade all science inquiry find equal application in the study of planet earth; they may be used to provide criteria for the organization and selection of content. It is strongly suggested that division of the field into its contributory disciplines (geology, meteorology, etc.) be avoided in order that prime focus remain with the planet as a whole.

B. THE SCIENCE PROGRAM -- GRADES 7, 8 and 9

In California schools, grades 7-9, required instruction in science varies from none to three years. As educators and parents have searched for ways to provide science in the already crowded curriculum, many patterns have developed. Thus, little uniformity exists in California where the amount and time in science instruction is the prerogative of the local district maintaining junior high schools. Schools of all types with grades 7, 8 and 9 have introduced a variety of new approaches to science instruction. Some specialized courses are offered in lieu of the traditional "general science course." In some junior high schools superlative science instruction in ultra-modern classroom-laboratories may be witnessed. It is hoped that all schools will evaluate the modern kind of science instruction offered, making use of the many resources available, and also of inservice education activities developed at the local level.

THE STATUS OF SCIENCE IN GRADES 7-9 IN CALIFORNIA

In an encouraging number of elementary school districts there is a progressively improving and coordinated program of science instruction in grades K-6. The emphasis is modern and is on inquiry, on problem solving, and on the observation of variety and pattern in nature leading to concepts of classification. Some county departments have produced extensive and excellent materials describing the natural history of their areas. Examples of this are seen in the monographs produced by the counties of Sacramento, San Diego, and San Luis Obispo. Field trips to parks, rivers and beaches are provided. Many children upon completing the sixth grade have acquired a tremendous interest in the things and the ideas of science. This interest should be kept alive.

For the seventh and eighth grades of the K-8 schools, Education Code Section 7604 designates that there shall be science instruction. The type of instruction and the time to be devoted to such instruction, however, are not designated. As a result, the amount and the quality of science taught are diverse. The Education Code makes no specific stipulation regarding the requirement of science instruction in those schools organized as junior high schools. Due to the pressure of other legislated mandates, the obvious need for elective offerings, and the prevalence of the "six period day," science instruction is often neglected.

In more than half of the junior high schools of the state, science is not even offered as an elective in the seventh grade. Most districts require two full semesters of science in the eighth grade. In certain large districts, counseling has resulted in most ninth grade students taking one additional semester of science; those students who are science-oriented may elect another semester of science during their three years in junior high. Science is usually offered as an elective in the ninth grade of the four-year high schools.

Beliefs previously expressed in terms of what is best for the student indicate that continuous science instruction is desirable. This should be the basic criterion for curriculum development.

In striving toward the ideal it is expedient to consider:

1. Special problems unique to the junior high school (grades 7, 8 and 9)
    a. The roles that junior high school science should fulfill
    b. The nature and background of the student
2. Current trends in science instruction in grades 7-9
3. Some curriculum projects now in existence
4. Course content and organization

SPECIAL PROBLEMS UNIQUE TO SCIENCE INSTRUCTION, GRADES 7, 8 and 9

The Roles that Junior High School Science Should Fulfill

The importance to the student of understanding science today is comparable to the importance of being able to read, to write, and to have skill in mathematics. The program of science instruction in grades seven, eight and nine should:

1. Serve as a transition between elementary school science and the somewhat discrete disciplines of the senior high school program. As a transitional program, junior high school science should not be an isolated unit, but should provide for continuous development of the objectives previously described for all science instruction.

2. Give structure to the fragments of scientific facts and principles that the student has previously acquired.

3. Help young people explore the fields of science in terms of possible vocations, avocations, and future science courses.

4. Provide an overview of science and technology for the student for whom junior high school science may prove to be terminal.

5. Serve as prerequisite for senior high school science. Special emphasis should be upon basic concepts in the physical science area. There are three primary reasons for this emphasis:

   (a) Whereas 85 percent of the students currently register for biology in senior high school, only about 35 percent study either chemistry or physics. This places more responsibility for insuring a comprehensive view of science upon the junior high school program.
   (b) The specific disciplines are relying upon the junior high school to provide background material.
   (c) In grades K-6 natural history and related factual information are studied. Teaching the ecology of the local area is standard practice. This formerly constituted a large part of the general science program.

The Nature and Background of the Student

Preparation of science curricula for grades 7-9 must take cognizance of the background and characteristics of the junior high school students. In brief, these students:

1. Have had substantial exposure to science and its technology. Today's seventh grader is more knowledgeable, more interested, and more concerned about science than were his parents a generation ago.

2. Have diverse elementary school science backgrounds. Some backgrounds may be described as superficial, some as factual, and others as based upon an inquiry approach.

3. Arrive at grade seven with considerable experience and skill in mathematics and reading. The extent of these skills is improving but the degree of mastery varies with the individual. Curriculum planners should build on these previous experiences.

4. Have a wide range of individual mental and physical capabilities. This also implies the need for ability-grouping for most effective instruction, but no single pattern of class organization fits all situations.

5. Have a limited span of attention and tend to be restless. Therefore active participation by the student in laboratory-centered, investigative, science-experiences is a most effective approach to instruction.

6. Have a high concern for themselves as individuals, for their peers, and also for the ever enlarging environment of adult life. The student asks: Who am I? What can I do? What am I good for? Science courses provide the student with the opportunity to explore his abilities and skill in their comparative interrelationships with fellow adolescents and within the immediate environment.

7. Try to achieve personal independence and at the same time maintain security. These students are becoming more able to define and work on tasks of their own choosing. This is a time for both individual and group activity.

8. Have increasing ability to relate facts and isolated bits of information to concepts and broad areas of learning. This ability to conceptualize and relate makes possible the organizing of science instruction in terms of major principles, key ideas, or broad themes. By junior high school age, students are more able to see relationships within the sciences, and between sciences.

9. Have interest and enthusiasm in seeking information and answers to problems. In essence, the early adolescent wants to learn. For him this is an "age of discovery and decision." Investigative experiences in science provide opportunities to explore and develop skills of inquiry.

In view of the foregoing description of the junior high school student, and although it seems clear that administrators should establish course-organization which best fits the student and the local situation, planning the program also should be considered in relation to the modern trends that are current in junior high school science instruction.

TRENDS IN BASIC SCIENCE TEACHING, GRADES 7-9

- There is increased emphasis on science instruction for all students in junior high school, i.e. in grades 7-9.

- More time is being allocated for science in the daily schedule. It is both significant and alarming to note that, in some schools, the 1963 legislated requirement of a foreign language has reversed this trend.

- Course content is being upgraded:

  (1) Much of the descriptive material of senior high school science courses is now included at the junior high school level.
  (2) Theoretical concepts are being introduced.
  (3) There is more concern with reporting formulation, and statistical treatment.

- There is increased use of investigative laboratory work as a means of learning and more emphasis is placed on individual inquiry.

- Team teaching, using teachers who are specialists for different parts of the course work, is finding increased use.

- Curriculum studies at all levels -- from the diligent efforts of individual teachers, to district-supported studies, and to nationally sponsored programs -- are underway. A wide variety of course outlines will evolve. It is difficult to find a stabilized program in this area of general flux! Teachers and curriculum specialists should be cognizant of and should keep informed about these studies.

JUNIOR HIGH SCHOOL SCIENCE CURRICULUM STUDIES

In Chapter VI the major, nationwide projects for the improvemer of science instruction in the senior high school are discussed. The projects deal with the specific disciplines of physics, chemistry ar biology. Development of the earth science project of the American Geological Institute is well underway. This project is planning materials for inclusion in the curriculum as ninth grade science.

Several junior high school projects are in the developmental ar testing phase. All projects have taken into consideration the natur of the junior high school student; all are following the specific trends. These projects are too numerous and too diverse to permit detailed descriptions. However, two examples will serve to illustra the work that is being done.

The Princeton Junior High School Project

A study developed at Princeton University, Dr. Frederick R. Fer Director, deals with a one-year program of "investigating the physic world." The title is Time, Space and Matter. This project is interesting because the test-classes across the nation are selected from all three grade levels. The emphasis is primarily investigati in nature, and hence is strongly centered about individual and grou experiments. For some organized experiments, relatively inexpensiv kits have been prepared. With these kits the home, as well as the classroom, may become the student's laboratory.

The three parts of the course are thematic in character. Part is called "On the Nature of Things," Part II, "Seeking Regularity i Matter," and Part III, "Interpreting a World of Change." The curric materials allow for flexibility of use and adaptation. The princip illustrated and the experiments devised are primarily physical in nature.

Science in Action

Science in Action, a guide for teaching science developed by the Department of Public Instruction of the Commonwealth of Pennsylvania, is illustrative of a very specifically structured program of science teaching, K-12. Based upon a comprehensively planned elementary program, the curriculum designed for the junior high school years is noteworthy for its specificity. Repetition of the work presented in elementary school is avoided. Also, teachers are admonished to not bring existing course material from senior high school subjects into the junior high school. Where overlapping does occur, the emphasis is upon allowing for far greater depth of study at the senior high school level.

In Pennsylvania the sequence that is strongly recommended for all junior high schools is:

1. For Grade Seven -- emphasis on the life sciences, including an introduction to plant, animal, and human biology.
2. For Grade Eight -- emphasis on the physical sciences and engineering.
3. For Grade Nine -- emphasis upon earth and space science as the first of a four-year sequence of specific disciplines studied in depth.

Of special interest in the Pennsylvania plan is the arrangement whereby students of high ability may be permitted to accelerate their science programs while still in elementary school. Slower students, conversely, are permitted to extend their junior high school science program through the tenth grade. Such a plan necessitates fairly rigid designation and requirement of science subject-matter to be covered. Methods employed stress the thematic approach, inquiry techniques, problem solving, and laboratory work.

COURSE CONTENT AND SEQUENCES OF INSTRUCTION

In California with its broad geographical, cultural, and industrial diversification, no single program of junior high school science instruction for all students is desirable. In order to serve individual student needs, some school districts have developed excellent curriculum materials. Fundamental objectives are in agreement and trends are comparable. Concerted effort is being directed toward improvement of the program of science instruction. Figures V-1 and V-2 present two examples of ongoing sequences of study. The first is from a district with junior high schools. The second is from a district having K-8, 9-12 organization.

Figure V-1

REPRESENTATIVE SEQUENCE OF PRESCRIBED SCIENCE-COURSE CONTENT*

(District with Junior-Senior High School Organization)

	UNIT I	UNIT II	UNIT III
Grade 8 Fall Semester	(3-4 weeks) INTRODUCTION WAYS OF THE SCIENTIST What is Science? Fields of Science Accuracy of Our Judgments Methods of the Scientist Tools of the Scientist	(3-4 weeks) BUILDING BLOCKS OF THE UNIVERSE What is Matter? General Properties of Matter States of Matter How Materials Are Put Together How Matter Can Be Changed Physical Changes Chemical Composition of Matter	(9-10 weeks) AN INTRODUCTION TO LIVING THINGS Activities of Living Things Conditions of Life Building Blocks of Life Functions of Human Body
Grade 8 Spring Semester	(6 weeks) MAN AND SPACE What Our Universe is Like What Our Solar System is Like Satellites and Space Travel	(5-6 weeks) OUR CHANGING EARTH Introduction to Geology The Earth's Crust Forces at Work on the Land Earth History	(7-8 weeks) INTERRELATIONSHIPS OF LIVING THINGS Environment and Kinds of Living Things Structure and Function of Living Things Communities of Living Things
Grade 9 Either Semester	(10-12 weeks) ENERGY The Nature of Energy Structural Relationships of Matter and Energy Energy and Wavelengths	(3-4 weeks) METEOROLOGY Heat Energy and Weather Nature of the Atmosphere Weather Measurements and Their Use Greater Weather Patterns	(3-4 weeks) FRONTIERS OF SCIENCE Oceanography Exploration of Space New Developments in Biology
Grade 9 Spring Semester	Diversified program offered as an elective for accelerated students and for science-oriented students. Curriculum materials are being developed.		

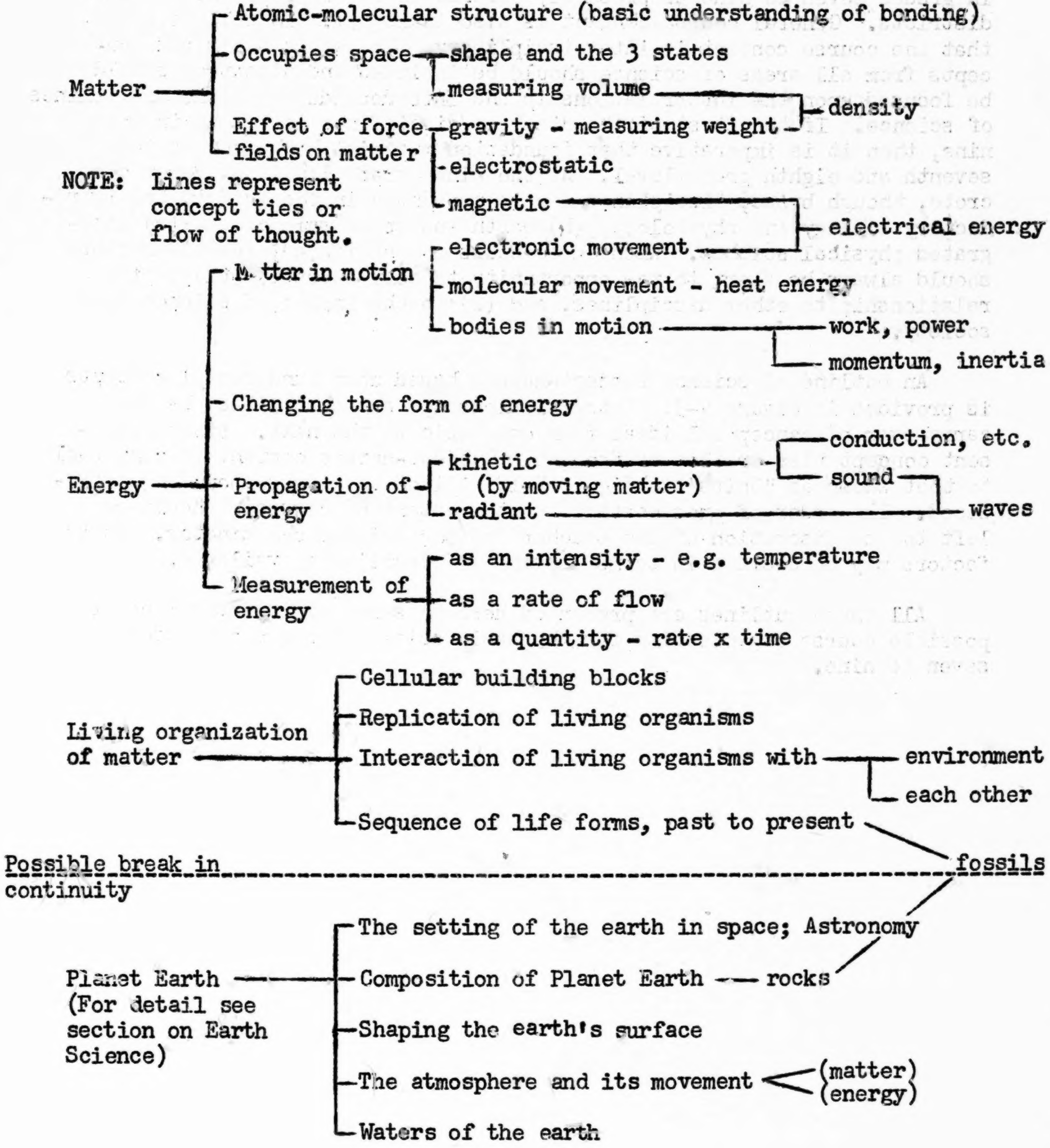
*Science is not offered in the seventh grade.
Considerable flexibility is allowed.
Time devoted to individual (or small group) laboratory work varies from 0 to 40 percent.
Program is organized on a basis of units of instruction.

Figure V-2. REPRESENTATIVE SCIENCE OFFERINGS IN GRADES 7, 8 and 9

(District with K-8, 9-12 Organization)

Grade 7 (Science required of all students)	1. Emphasis upon biological science with much reference to the student and his health. 2. Seventh grade State Textbook used; supplemented by State Health Text. 3. Teaching by inquiry is encouraged. 4. Student involvement accomplished with group projects.
Grade 8 (Science required of all students)	1. Emphasis upon physical science areas. Earth science concepts developed. 2. Eighth grade State Textbook used; a supply of two ninth grade texts, general science textbooks, is available for reference assignments and collateral reading. 3. Demonstration experiments requiring student participation are used extensively.
Grade 9 (Science elected by 50% of students)	Course A. Principles and Techniques of Science 1. Designed to: a. meet the needs of average and above average students. b. teach laboratory skills, and c. provide foundation experiences for the disciplines that follow. 2. Extensive emphasis upon individual experience in: a. general laboratory procedures and report writing. b. procedures used in chemistry. c. procedures used in physics. d. an open-ended project for each student. e. mathematical interpretation of data. f. use of reference material. 3. Curriculum materials developed by teachers of the district.
	Course B. High School General Science 1. Designed to meet the needs of: a. the slow learner. b. the student who did not have the advantage of the comprehensive science instruction of grades seven and eight. 2. Course structured to be comprehensive, containing units from all major areas of science. 3. There is extensive use of demonstrations and films. 4. Ninth grade general science text supplemented with collateral reading materials.
	Course C. Biology-XL 1. Designed for the accelerated students 2. Uses BSCS - Yellow Version, modified

Figure V-3 A CONCEPT FRAMEWORK FOR SCIENCE INSTRUCTION--GRADES 7-9



- Matter
  - Atomic-molecular structure (basic understanding of bonding)
  - Occupies space
    - shape and the 3 states
    - measuring volume — density
  - Effect of force fields on matter
    - gravity - measuring weight — density
    - electrostatic
    - magnetic — electrical energy
- Energy
  - Matter in motion
    - electronic movement — electrical energy
    - molecular movement - heat energy
    - bodies in motion
      - work, power
      - momentum, inertia
  - Changing the form of energy
  - Propagation of energy
    - kinetic (by moving matter)
      - conduction, etc.
      - sound — waves
    - radiant — waves
  - Measurement of energy
    - as an intensity - e.g. temperature
    - as a rate of flow
    - as a quantity - rate x time
- Living organization of matter
  - Cellular building blocks
  - Replication of living organisms
  - Interaction of living organisms with
    - environment
    - each other
  - Sequence of life forms, past to present — fossils

Possible break in continuity — fossils

- Planet Earth (For detail see section on Earth Science)
  - The setting of the earth in space; Astronomy — fossils
  - Composition of Planet Earth — rocks — fossils
  - Shaping the earth's surface
  - The atmosphere and its movement < (matter) (energy)
  - Waters of the earth

NOTE: Lines represent concept ties or flow of thought.

The preceding outlines show acceptable sequences of science courses in grades seven to nine as presently offered in two representative school districts. General course content is also indicated. It will be noted that the course content is interdisciplinary. The basic facts and concepts from all areas of science should be included and attention should be focused upon the interrelationship and interdependence of the disciplines of science. If the first of the discrete disciplines is taught in grade nine, then it is imperative that foundation material be taught at the seventh and eighth grade level. At the ninth grade level the first discrete, though broad, disciplines may be presented in the form of (a) introductory biology and physiology, (b) earth and space science, or (c) integrated physical science. When these courses are offered, the instructors should always be alert to the opportunity to call attention (1) to the relationship to other disciplines, and (2) to the impact of science upon society.

An outline of science subject-matter based upon fundamental concepts is provided in Figure V-3. Interrelationships are established by the carry-over of conceptual ideas from one topic to the next. Lines represent concept ties or flow of thought. Subject-matter content is comparable to that shown as "Units" in Figure V-1. All of the ideas should be introduced. The order of presentation and the extent of coverage should be left to the discretion of the teacher and the science coordinator. These factors may be decided in terms of time and facilities available.

All three outlines are presented here to serve as illustrations of possible course organization for the basic science program of grades seven to nine.

Chapter VI

SPECIAL STUDIES IN SCIENCE CURRICULA

There are several nationally sponsored studies in science curricula. Four of these studies, though only three to six years old, are so well established that their impact on education in physics, chemistry and biology has become of major nationwide importance. These four programs are known as the Physical Science Study Committee (PSSC), the Chemical Education Materials Study (CHEMS), the Chemical Bond Approach Study (CBA), and the Biological Sciences Curriculum Study (BSCS). These four studies are reviewed in some detail so that they may be noted by science teachers and administrators throughout the State. Those concerned with science teaching and with curriculum development should acquaint themselves with the progress of these and other evolving programs. The purpose of giving detailed descriptions of these studies is to indicate the central ideas which each is attempting to develop, and the organizing principles around which each course of study is centered. The review may stimulate development of even more effective patterns of science instruction.

The analysis of the rationale for each study was taken from articles and publications by proponents of the respective studies. Each of these four major programs was planned specifically for the type of student who has traditionally registered for physics, chemistry and biology. The programs basically do not represent new courses; they provide special emphasis and new approaches to accepted courses. With enthusiastic dedicated teachers, properly trained, very favorable results are being achieved. Additional new approaches will be devised. Additional studies such as the Earth Science Project are underway. An ever greater percent of the student population will be reached. The best has certainly not yet been achieved.

The four programs: (1) treat science education as a method of inquiry; (2) use themes to interrelate subject matter; (3) stress the necessity for mastery of fundamental principles; (4) emphasize the need for more laboratory experience for each student; (5) encourage an investigative type of laboratory experiment in preference to one that confirms information; and (6) are selective and provide depth at the expense of breadth.

THE PSSC CURRICULUM

I. For Whom Were the Materials Designed? The PSSC physics material is designed for academically superior, university-bound students (roughly the top one-fourth of a class). Physics for these students is developed as if it were their terminal course in the subject. Preparation for college physics is a desirable, but secondary, goal.

II. The Structure of PSSC Physics. Science is described as an intellectual process. The curriculum materials are devised to develop the tentative nature of all physical knowledge; and to this end, theories and experiments alike are presented as processes of successive approximation. The subdivisions of physics are developed as aspects of a single discipline. Interconnections of physics with the fields of biology and chemistry are introduced frequently. Great weight is given to the major principles of physics that unify the subject. Emphasis is placed on the development of theory in physical knowledge.

A. Inquiry in PSSC Physics. The curriculum materials have been developed to reflect the spirit of inquiry: The why, how, significance, usefulness, and reliability of physical measurements are equally important to the fact. This conception pervades the teaching, the text, the laboratory outline, and the films and other supplemental materials. All these fit together into a total curriculum design. The "idealized" physical model with its advantages and limitations, is used as a concept to interrelate laboratory and other phases of study.

B. Thematic Development. Selected general principles of physics have been woven into a sequential pattern; different teaching media are used as they are appropriate. A single coherent picture of matter is established through interrelating wave mechanics, energy, momentum and electrical forces; it is shown how these forces are convertible into one another, still maintaining the laws of conservation. Thus, thematic relationship is used and the course materials reflect the world as it appears to the professional physicist. In this treatment the nature of modern science and the nature of physical inquiry are central. "Intellectual activity" of physics is selected in preference to the technology derived from the science.

C. Key Ideas. The basic concepts of time, space and mass are developed, using the major thematic idea of the wave-mechanical explanation of the internal structure of atoms. These concepts are not developed by defining them, but instead by demonstrating the manner in which they are handled by physicists. Thus, one subplot develops a concept of wave behavior, treated as a part of the study of light. The experimental consideration of a particle-model of light proceeds until it reaches its limitations and must be rejected. Then a new approach is made through the behavior of waves in a wave model of light. Another subplot is in the development of Newtonian mechanics. The conservation laws of momentum and energy are stressed more than usual. Mechanics is treated dynamically, with statics as a special case. The synthesis of wave behavior and particle mechanics in describing the atom connects the two subplots. Here, again, the student faces the basic concepts of space, time, matter, and motion.

III. The Role of the Laboratory. In PSSC physics the laboratory is used for the performance of real experiments. The experiments are open-ended when possible. The laboratory is used to provide observations, to generate ideas, and as a source of data from which "models" may be developed. It is recommended that laboratory work should precede the use of the text when possible. Laboratory work is designed to test those "models of explanation" that have been developed. The laboratory program is not intended to elicit for the student an inductive knowledge of all of the fundamental laws of physics; even if this were possible, it would be uneconomical. Whenever possible, laboratory work should be quantitative in nature. An understanding of and appreciation for the nature of evidence are objectives of this laboratory program.

IV. Other Instructional Methods. A carefully controlled management of the various modes of instructional practices characterizes the materials developed for physics teaching by the PSSC. The laboratory is used most extensively in the earlier part of the course of instruction and progressively decreases with corresponding increase in the use of films. The films have been especially designed to deal with experiments for which classroom equipment does not exist or is not practical for high schools.

The foregoing statements are based upon information available from:

Physical Science Study Committee; Educational Services, Inc.,
164 Main Street, Watertown 72, Massachusetts.
Jerrold R. Zacharias, Director

THE CHEMS CURRICULUM

I. For Whom Are the Materials Designed? The Chemical Education Materials Study was formed to develop text, laboratory, and other instructional materials for the general student who takes high school chemistry, as well as providing challenging problems and experiments for the gifted or upper part of the typical high school class. CHEM Study then is designed for only about one-third of the students.

II. The Structure of CHEMS' Chemistry. Great emphasis is placed on the experimental nature of chemistry. This emphasis has been developed because the CHEM Study views experimentation as a means of providing a basic understanding of science and as a means of giving a clear view of the way in which science advances. In general, laboratory experiments precede discussion. Careful observation, accurate records, and "wondering why" the data are as they are leads to the development of explanatory schemes, or consideration of available models. In this way, laboratory experiments provide the basis for discussing and understanding the basic principles of chemistry. Conceptual models are used to tie together experimental results in such a way that students may view the growth of scientific knowledge both in accumulated facts and in broadened concepts.

A. Inquiry in CHEM Study. Since laboratory observations leading to an attempt to answer the "why" of results is a primary plan of CHEMS' procedures, it follows that extensive use of inquiry techniques is employed. In addition to inquiry, the student is made aware of the inevitability of experimental error and of means for evaluating experimental error. Students explore alternate models for interpreting experimental data. They are thus assisted in understanding the ways in which chemists choose among such alternative explanatory schemes.

B. Thematic Development. The CHEM Study views chemistry as essentially an experimental science. The nature of laboratory experimentation, the assessment of experimental error, and the development of explanatory schemes are central themes of the CHEMS' materials. Critical selection of laboratory experiments has been made, specifically, in order to develop certain major concepts and key ideas in the field of chemistry.

C. Key Ideas. The laboratory and text materials are selected and arranged sequentially to provide a means for developing seven selected concepts in the field of chemistry:

1. the atomic theory
2. the conservation laws
3. the kinetic theory
4. the periodic table
5. energetics
6. equilibrium
7. atomic and molecular structure

The text may be discussed conveniently in three sections. In the first section the students are given an overview of chemistry. The students gain some familiarity with scientific methods and models, and with such concepts as uncertainty in measurement, phase changes, chemical reactions, energy, molecules, the mole, conservation of atoms, kinetic theory, the electrical nature of atoms and ions, and chemical periodicity.

The second section of the course investigates the major generalizations which have been listed above. Starting with a closer look at energy effects, rates of reactions, and chemical equilibrium, these ideas are then applied to solubility, acid-base chemistry, and oxidation-reduction. Atomic structure and bonding are treated in some detail. Molecular architecture, properties of substances, and the periodic table, are predicted and explained in terms of structure and bonding.

The final section uses organized descriptive chemistry as a means of applying and reinforcing the concepts developed earlier.

III. The Role of the Laboratory. The CHEM Study approach to chemistry is based upon a philosophy that the high school laboratory should be a place where the student makes and records careful observations, seeks "regularities" in what he observed, and then "wonders why." The CHEM

Study laboratory typically poses questions to which the student has not seen the answer and provides him with equipment, incentive, and general guidance in searching for answers to the questions. On the basis of the information which he collects, he proceeds towards generalizations, using his own data and those of his colleagues. Class discussion typically follows the laboratory work and builds directly upon it. Thus, the laboratory time is not spent in demonstrating ideas which the student has already accepted, but in raising and answering questions which have not yet occurred to him, or at least which have not yet been answered.

This approach is fostered by presenting the student with a blank laboratory notebook in which he must record all his observations and organize his own data. The majority of the experiments are quantitative. Thus, each student obtains numerical data which he must manipulate, comprehend, and generalize upon. The mathematical background required is not great. What is required is a feeling for the relationship between numbers and physical observation. The validity of the numbers is judged through the student's estimate of experimental error and through comparing his own results with those of his classmates. The atmosphere in the CHEMS laboratory is, accordingly, informal but businesslike.

IV. Other Methods of Instruction. The text is thoroughly dependent upon and integrated into the laboratory experiments, with supplemental use of films. An extensive set of films, integrated with text and laboratory work, has been prepared. Concepts developed early in the learning sequence are utilized throughout the year. Series of learning cycles are established for producing growth in understanding.

The CHEM Study Committee hopes that when a student leaves the course he will think of any chemical system with which he comes in contact in terms of the structure of the system. Structure means not only electron structure but the geometrical arrangement of the atoms, their relative sizes and shapes, the packing together of atoms and molecules, the forces between them, and how these affect their chemistry. It is hoped he will also think in terms of dynamics. The student will not only have organized a great deal of factual information, but just as important, he will be able to interpret his own new observations in terms of these concepts of structure and dynamics.

The foregoing statements are based upon information available from:

Chemical Education Material Study; Lawrence Hall of Science,
University of California, Berkeley, California.
Dr. Richard J. Merrill, Executive Director.

THE CBA CURRICULUM

I. For Whom Are the Materials Designed? The text and laboratory materials prepared by the CBA project were designed for students who are currently enrolled in chemistry at the high school level. The approach to the teaching of chemistry was developed by a group of high school and university teachers who felt that the present course structure in high school chemistry was not in keeping with modern concepts of the nature of chemistry as an intellectual discipline.

II. The Structure of CBA Chemistry. In their organization of the CBA curriculum, the developers concluded that, to give the students a vital and true picture of chemistry, the subject could be organized and presented through the exploration of three key points:

1. Chemists work in the laboratory to obtain data.
2. Chemists use imagination to develop ideas.
3. Chemists combine experimental data and imaginative ideas to further their understanding of chemical systems.

The text, CHEMICAL SYSTEMS, and the laboratory manual, INVESTIGATING CHEMICAL SYSTEMS, written for the CBA course, were prepared with this precept in mind.

A. Thematic Development. A most important strategy in developing an understanding of chemistry is that of getting the student to bring facts and ideas together. Chemistry is not solely experimental nor solely theoretical but a process involving both observations and ideas. The basic themes of the CBA materials are developed around the idea or the central theme of chemical bonds; to a large extent the properties of chemical substances are correlated or understood through consideration of the bonds between the atoms that compose each structure. The three thematic ideas involve structural models, kinetic-molecular theory, and energy.

A good deal of attention has been given in the course to the use of theoretical models and of actual three-dimensional geometric models in chemical reasoning. Models are developed as a way in which experimental data can be interpreted and are then used deductively to predict future happenings. Throughout the course, there is emphasis on the continuity of the arguments of chemistry. The models and tools developed are reapplied to the investigation and interpretation of new systems, resulting in modification of the previous models and the development of new ones. This development is sometimes inductive and sometimes deductive in an effort to reflect the ways in which science develops. Through the texts and the laboratory program most of the topics normally included in high school texts are treated, not as individual entities but rather as interconnected threads of the total fabric of chemistry.

B. Key Ideas. The key ideas of the curriculum materials developed by CBA, as previously indicated, are oriented around three major conceptual schemes. Students begin with the so-called "charge cloud model" in which, for simplicity, the electrons are assumed to behave as spheres with uniform distribution of charge. This model is used as a deductive tool and leads to the development of the "rule of two" and the "rule of eight." The inability of any structural model to account for the states of matter leads to a second scheme or model, the kinetic-molecular theory. Building random and continual motion into the structure-system provides for changes in state in response to changes in temperature. From the "charge cloud model" the concept of hybridized atomic orbitals is finally evolved and models are shown.

The ideas of atomic structure and of the kinetic-molecular theory are then applied to a systematic analysis of several reactions, with major attention devoted to the methane reaction with oxygen. Electrostatics is introduced as a subtheme and related quantitative concepts are introduced. The relationships involving energy are introduced and the energy-concept becomes a major theme.

When the first chemical reactions are introduced as laboratory phenomena, it is pointed out that a temperature change accompanies a chemical change and that this observation can be interpreted in terms of energy. Increasing uses are made of the concept of energy but it is not until the middle of the course that energy is presented as an organizing idea of great use to the chemist.

Other threads can be discerned in the fabric of the curriculum materials. Those selected for mention above give some idea of how they serve strategic purposes for the presentation of materials of instruction to students. It is most important, however, that these be more than teaching strategy. The student should see the importance of organizing his own information. He should recognize not only those parts which fit neatly together but also tag-ends which are often intriguing because they do not quite fit.

C. Inquiry in CBA Chemistry. The CBA course is designed to get the student personally involved in investigation and interpretation of chemical phenomena. The experimental and the theoretical materials with which he deals are developed with this goal in mind. Theories are developed, not presented dogmatically. Laboratory work is used to raise questions. Data are presented both to show the power of ideas and also to show the incomplete character of present day knowledge about chemicals.

III. The Role of the Laboratory. Informal laboratory work is an integral part of CBA chemistry. Laboratory work is intended to develop the student's ability to investigate chemical systems. Experiments are designed to be problems with puzzle-like qualities that are to be solved by the students through observation and logic. Many of the experiments are new and have been especially designed for secondary school use. The purpose of an experiment is not to verify a foreknown answer to a designated question but is to provide data which enables the students to propose a logical argument to support his solution for the problem posed. Considerable attention is given to first obtaining and then interpreting quantitative data. Graphs are used extensively.

The CBA curriculum materials recognize three central functions of the laboratory: (1) to obtain experimental data, (2) to explore ideas, and (3) to promote independent investigations. The emphasis in the laboratory program is placed on the relationship between (1) the structure of a substance and its properties, (2) on the energies associated with chemical systems, and (3) on the pathways of chemical reactions. The laboratory activities present chemistry to the students as an experimental science in the hope that the student will see chemistry as a practicing chemist sees it. Vertical development of ideas and concepts, and of laboratory operations and selection of specific experiments, is intended to help the student see that his laboratory work leads somewhere rather than being a series of isolated tasks.

IV. Other Methods of Instruction. In CBA chemistry a problem is introduced. Some information from the laboratory and some from the literature is fitted into a logical scheme based on a set of assumptions and often some theoretical model. Reasoning leads to a possible solution to the problem. In most cases either the solution to the problem or some of the difficulties encountered will suggest still other paths to be explored. Because chemistry is seen as a rather tightly organized discipline, the interrelationship of laboratory, theoretical model, and plausible explanation must follow a carefully planned sequence. Adequate time and preparation should be made for pre-laboratory discussion and for carefully developed post-laboratory discussion. These procedures are considered fundamental to the introduction of students to scientific thinking.

The foregoing statements are based upon information available from:

Chemical Bond Approach Project; Earlham College, Richmond, Indiana.
Laurence E. Strong, Director.

THE BSCS CURRICULA

I. For Whom Are the Materials Designed? General education in biology at the high school level has been the major focus of the Biological Sciences Curriculum Study. Early in the study it was recognized that most high school students take a course in biology at the tenth grade and that for most of these students the biology course is the only science course that they will take in high school. Evaluations of the BSCS materials have been assessed by the BSCS as being suitable for all but the lower 20 percent of students who are currently taking biology at the tenth grade level.

A sound biological understanding is considered by BSCS to be the inalienable right of every child who, when adult, will need to cope: with individual problems of health and nutrition; with family problems of sex, reproduction and parenthood; with the citizen's problems of wise management of natural resources; with the biological hazards of nuclear agents in peace and in war; and with governmental support of science as the primary source of national strength and well-being in the scientific era.

II. The Structure of BSCS Biology. The proponents of BSCS recognize that the life sciences are so diverse -- in content, in point of view, and in methodology -- that there is no single best way to organize a high school course in biology. Within this diversity, the nature of science and the nature of biology as a science become increasingly important. Whatever approach and whatever type of organization are used the essential character of scientific activity, and the several great biological themes must permeate the treatment. The structure of biology as interpreted and developed by BSCS materials includes nine pervasive themes treated at each of the levels of biological organization. As shown in Figure VI-1, seven levels of biological organization are considered, and a third dimension is added by considering the major classification of living things.

A. Inquiry in BSCS Biology. Of primary importance in the study of biology is the learner's comprehension of the nature of the process whereby knowledge increases and whereby man acquires new understandings of life and his universe. This philosophy is one of the cornerstones upon which BSCS biology has been built. Wherever possible, text presentations and laboratory observations have been related to inquiry methods.

B. Thematic Development. The BSCS, consisting of a large group of research biologists, teachers of biology at the secondary school and university level, and science educators, identified fied nine major themes, or key ideas, which they felt should be woven through instruction in biology. These themes, together with the levels of biological organization previously discussed, provide a lattice for the selection of content and the kinds of instruction that lead to an understanding of modern biology. The nine themes are:

1. Change of living things through time -- evolution.
2. Diversity of type and unity of pattern of living things.
3. Genetic continuity of life.
4. Complementarity of organism and environment.
5. The biological roots of behavior.
6. Complementarity of structure and function.
7. Regulation and homeostasis: the maintenance of life in the face of change.
8. Science as inquiry.
9. The intellectual history of biological conceptions.

C. Key Ideas. The themes listed above become the key ideas for the selection of approach, content, and laboratory experiences. Because of the diffuse nature of the biological sciences three approaches to the organization of materials were developed. One approach is through ecology, a second through physiology and biochemistry, and a third through development and evolution. Within each of these approaches to biology the levels of biological organization and the themes form a framework.

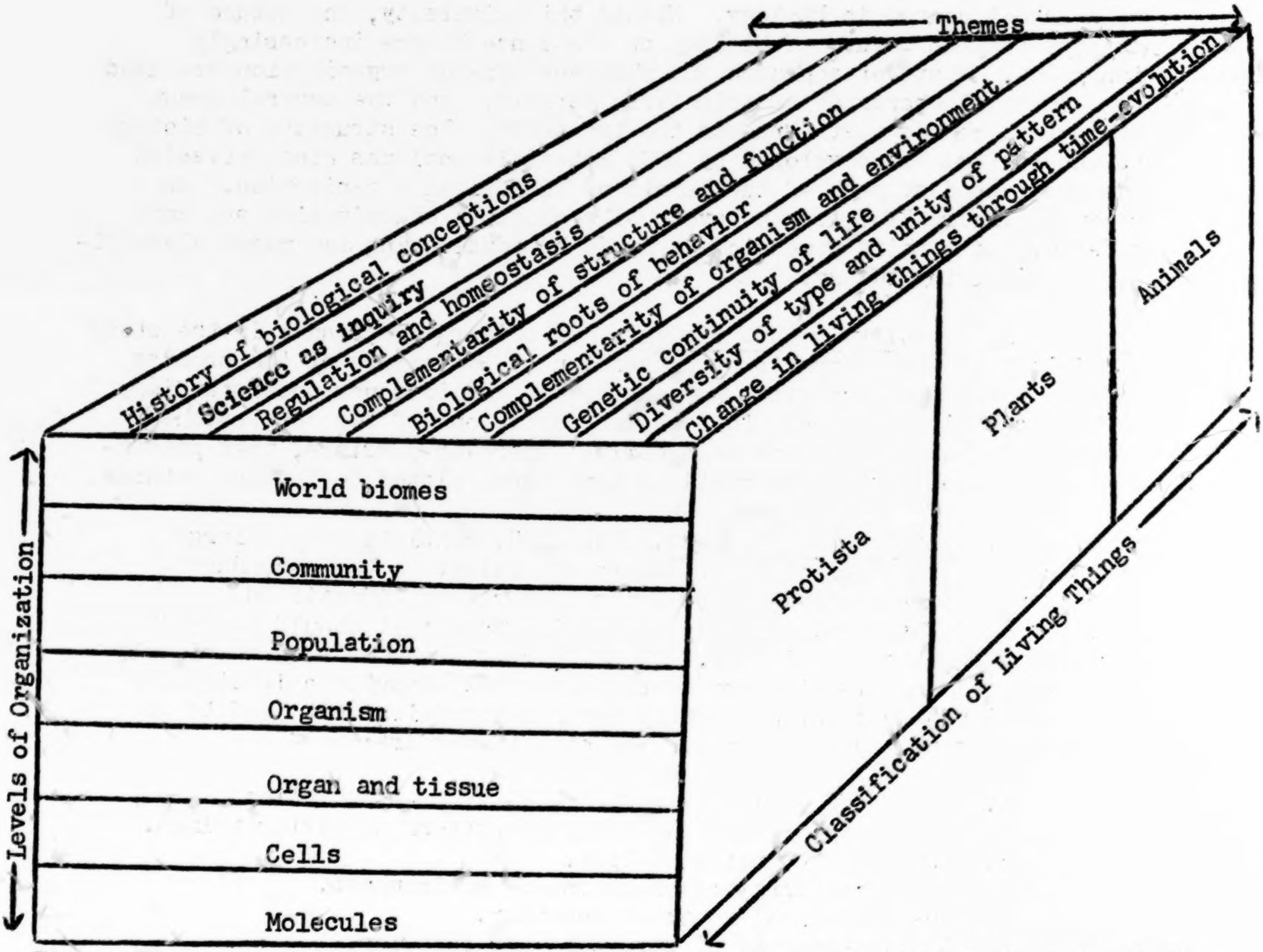

Themes
History of biological conceptions
Science as inquiry
Regulation and homeostasis
Complementarity of structure and function
Biological roots of behavior
Complementarity of organism and environment
Genetic continuity of life
Diversity of type and unity of pattern
Change in living things through time-evolution
Levels of Organization
World biomes
Community
Population
Organism
Organ and tissue
Cells
Molecules
Protista
Plants
Animals
Classification of Living Things

Figure VI-I. Graphic representation for the organization of biological knowledge.

The themes or key ideas lie relatively deep in the substance of biology. If we think of the facts as lying on the surface, and the subject-matter principles as lying beneath these facts, the nine BSCS themes and the levels of biological organization lie still deeper, and therefore constitute a more significant and profound setting forth of biological meaning. Each instructional block thus formed is subject to diverse interpretation and emphasis.

III. The Role of the Laboratory. Great stress is made on the laboratory as a major instructional tool. There is a deemphasis on illustrative types of laboratory exercises and a heavy use of investigative experiences which introduce the student to the inquiring processes of science. Open-ended experiments, a research approach, and the use of living rather than preserved organisms characterize the investigative laboratory. Students do less drawing, labeling, and question-answering than in conventional biology laboratory exercises and devote more time (1) to observations of living forms in controlled experimentation, and (2) to scientific communication, i.e. data collection, graphical interpretation, and relating observation to theory. Also, there is a corresponding departure from the idea that laboratory experiences serve mainly to "follow and illustrate the textual material." BSCS centers on the laboratory and considers all other course experiences as contributory to it.

IV. Other Methods of Instruction. In order to develop the nine themes and to reflect the processes of scientific inquiry, text and other written materials must reflect, through careful use of language and selection of content, the way in which biological knowledge has grown and developed. Discussion of the laboratory work with ample time devoted to the questions that the laboratory arouses is an essential part of the instructional pattern. With the major portion of class time devoted to laboratory and discussion, the assumption is made that the student will read the text and prepare for laboratory work outside of class. The development of techniques for self-instruction on the part of the student for this independent work outside of class is seen as the only practicable solution to the problem of "coverage."

The foregoing statements are based upon information available from:

Biological Science Curriculum Study; American Institute of
Biological Sciences, University of Colorado, Boulder.
Dr. Arnold Grobman, Director.

OTHER CURRICULUM STUDIES

In addition to the four well-established curricula that have been discussed at length, there are several others that are now proceeding with aid on a broad base of national grants. None of these studies has passed through the extended experimental trials and revisions enjoyed by the previously described programs. Curricula that are of especial interest are in the field of general science and earth science. They are significant because they are directed primarily toward course work in grades seven, eight and nine -- recognized as a critical area.

Those concerned with curriculum development should seek specific information regarding progress in subject areas of special interest. Probably the most comprehensive summary of ongoing programs published (May 1, 1963) is Information Clearinghouse, a joint project of Science Teaching Center, University of Maryland and the American Association for the Advancement of Science. This is available through the project director, College Park, Maryland.

Additional and specific information may be obtained from the National Science Foundation, the National Science Teachers Association, the United States Office of Education, the American Association for the Advancement of Science, and the Bureau of Secondary Education of the California State Department of Education, as well as from the directors of the specific projects.

CONCLUSIONS

The national studies in science curricula were conceived because of the realization that change and improvement are imperative in science instruction. The studies have rapidly matured under the guiding influence of forward-looking and dedicated teachers aided by substantial grants from the National Science Foundation and other agencies. The grants have provided funds for summer institutes and writing conferences designed (1) for the investigation and development of ideas, (2) for the training of teachers, and (3) for the writing of text material. The instructional materials have been subjected to extensive testing in actual classes in high schools across the nation. The phenomenal success of these programs gives evidence that a good creative idea backed by dedicated teachers and supported by ample funds will have far-reaching influence. For example: In the 1963-64 school year there are over 110,000 students studying CHEMS chemistry in over 800 high schools. These are amazing data for a program that was only started in 1960.

What then are the ingredients of these successful programs in different disciplines? What do they have in common?

In general, the courses are not new; they cover the same subject matter and are designed for the same groups of students who traditionally studied these courses. However, the curriculum materials developed are invaluable for improving secondary science instruction. Each of these curriculum study groups has been composed of scientists and science teachers who have spent extended time in developing rationales for instruction, and materials to support these rationales. Each group is currently evaluating and revising materials in the light of field trials. Change and improvement are continuing characteristics of these studies. They represent a great financial outlay and a major expenditure of skill and time. Specifically, for each of these studies:

1. the attention to thematic development provides for one potentially successful means for selecting, from all that could be taught, those understandings which might be taught within year courses in biology, chemistry, and physics at the secondary level.
2. the emphasis on the teaching of science as inquiry is of central importance in science education throughout the secondary school.

3. the deliberate confinement of attention to a limited number of key ideas for inclusion within a particular course of study is essential in order to reduce superficiality and to make possible the development of a more thorough and greater depth of understanding of these ideas.

4. the objectives and intent of the materials developed by the curriculum studies is more in harmony with the nature of scientific knowledge and its growth than materials which have been previously available.

5. the importance of inquiry-experiences in laboratory in developing an understanding of science receives strong emphasis. The development of open-ended laboratory problems to provide for potentially creative work by students is to be especially commended.

6. the pacing of instruction needs further attention. Wide variability among individuals and class groups may result in pressure to "cover the subject" at the sacrifice of developing understanding. This is especially true of those curriculum materials which form a tightly integrated sequence of experiences and ideas. This is another point that indicates the outstanding need for more extensive training of teachers.

7. the problem of selecting what to teach and how to teach it has not been solved for the full range of students. There is need for development and experimentation with patterns other than those which have now been planned. Probably this need to serve all students can only be solved by additional studies and the preparation of new programs. Certainly more consideration must be given to general education and also to the slower learners. For the more gifted students, the opportunity for advanced work is being provided in many schools. There seems to be little uniformity in such advanced offerings.

8. the achievement of goals proposed by the different curriculum studies remains uneven, as would be expected with experimental materials, and needs to be continuously assessed.

9. the Advisory Committee recognizes a need for evaluation of new courses. No adequate means of evaluating the success of a program objectively has been devised, although some attempts are currently underway.

10. encouragement should be extended to individuals and groups with new ideas for curriculum development. Admirable as are these new courses, and promising for the future, they should not be regarded as complete or exclusive. Further experiments are needed. Individual teachers should explore and school systems should encourage improvements and local creative developments.

Chapter VII

SUMMARY OF RECOMMENDATIONS

GENERAL

1. Science should be a vital part of the educational experience of every student. The public school system should provide opportunity for this experience.

2. All students should receive an overview of the complete fields of life and physical sciences. However, for students in grades 10-12 who have previously studied basic science concepts, it is desirable that the various disciplines be identified and studied separately and intensively.

3. There should be emphasis upon interrelatedness and interdependence of the several disciplines of science.

4. Attention should be given to the pacing of instruction so as to provide for the wide variability among individuals.

5. The secondary science program should articulate with the elementary school, with higher education, and with vocational training. Effective articulation, K-12, requires continuous professional leadership services which should be a function of the State Department of Education.

APPROACH AND EMPHASIS

6. The teaching of science as inquiry should be emphasized throughout the secondary school science program.

7. The thematic approach should be considered as a device for emphasizing the interrelatedness and interdependence of all science.

8. Selection of a limited number of key ideas to be studied in depth is advisable. This may lessen the tendency to attempt to cover too many topics with resultant superficiality.

9. Administrators, curriculum coordinators, and teachers should be cognizant of materials developed by the NSF-supported curriculum studies which are providing valuable guides and materials for improving secondary school science instruction.

10. Development of the science curriculum in grades 7-12 should parallel that of the mathematics curriculum so that the quantitative aspects of problem solving and the formulation of mathematical models in science will use and reinforce the skills and understandings of mathematics.

11. The science curriculum, of grades 7-9 particularly, merits consideration, strengthening, and evaluation and should receive special attention.

12. The needs of students in grades 7-8 can best be met through a program stressing basic science concepts, inquiry as a method of science, and the importance of investigative laboratory experiences. Grade 9 can continue the study of basic concepts or be devoted to the first of the discrete science disciplines such as earth science or biology.

13. Inquiry experiences in laboratory should receive strong emphasis in all grades.

ADMINISTRATION AND REQUIREMENTS

14. In grades 10, 11, and 12 it is very desirable that some of the laboratory sessions be longer than one school period. (Flexible scheduling and team-teaching arrangements make it possible to provide double laboratory periods.)

15. To meet the needs of the changing emphasis in science instruction, adequate facilities, equipment and materials should be provided.

16. The authority for establishing curricular minimums should be exercised by the State Board of Education; it is strongly recommended that specific legislative mandates be reduced.

17. To insure that science is included in a balanced program of education, the State Board of Education should, with the advice of its professional staff, evaluate and construct the minimum curricular requirements governing secondary school offerings.

18. In the field of science, it is recommended as a minimum that the State require every student during grades 7-12 to devote not less than the equivalent of twenty semester periods to the comprehensive study of the physical and life sciences. It is further recommended that the time be divided equally between the two areas of science with one-half the requirement to be completed after the student enters the tenth grade. All courses in science should provide laboratory experience, however a laboratory course in grades 10, 11, or 12 is regarded as the absolute minimum.

19. For all college-bound students, it is recommended that three years of science be required.

20. The opportunity should be provided for each student to complete the equivalent of six years of science in the secondary schools.

TEACHER SUPPLY AND TRAINING

21. College faculties are urged to provide proper guidance to encourage outstanding young men and women to enter science teaching.

22. Because continuous inservice training is essential for maintaining teaching effectiveness in the evolving science program, teachers must be given the opportunity and the incentive to maintain and increase their professional competence.

23. Teachers should participate actively in professional science organizations within their specialized field, and in organizations for teachers of science.

RESOURCES

24. In implementing the science programs, K-12, schools should take advantage of community resources such as business-industry groups, professional and technical societies, and field observations can provide.

25. Experimentation in new directions of curriculum development is encouraged. Time and facilities for innovations should be provided.